WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
2002-03 SALT PILOT PROJECT
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EXECUTIVE SUMMARY: During the winter of 2002-03, the Washington State Department of Transportation (WSDOT) conducted a field evaluation that compared several aspects of using sodium chloride for highway snow and ice control and corrosion-inhibited snow and ice control chemicals. Sections of highway were designated in which salt products (salt brine and rock salt) were the sole chemicals used. Similar sections of highway were designated in which corrosion-inhibited chemicals (corrosion-inhibited liquid calcium chloride, corrosion-inhibited liquid magnesium chloride, and corrosion-inhibited rock salt) were the sole chemicals used. The aspects evaluated included costs of program delivery, program results, environmental impacts, and corrosion.

The cost of materials, equipment, and labor for sections in which salt was used was significantly less than like costs for those sections in which corrosion-inhibited chemicals were used. Long-term costs such as those from corrosion to motor vehicles or adverse environmental impacts were not quantified due to the relatively short duration of this evaluation. However, indications of the nature of these potential costs were found from the corrosion and environmental evaluation information. The results, in terms of average roadway condition during inclement winter weather, were similar between highway sections where salt was used and highway sections where corrosion-inhibited chemicals were used. Maintenance crews using either category of snow and ice control chemical delivered a very high level of service throughout the winter season. They essentially provided bare pavement conditions throughout much of the winter season. These similarities will not occur in temperatures below 20 degrees Fahrenheit however as salt is generally not effective below this temperature. Alternative chemicals such as magnesium chloride ($MgCl_2$) and calcium chloride ($CaCl_2$) are effective at lower temperatures.

The corrosion evaluation provided varied results based on different scenarios. Corrosion was evaluated by exposing samples of steel, sheet aluminum, and cast aluminum to either salt or corrosion-inhibited chemicals and comparing corrosion rates on them. Exposure of the metal samples was accomplished by attaching them to maintenance trucks, maintenance Supervisor pick-up trucks, and roadside guardrail posts. The basis to which the corrosion results are compared is a performance specification used by WSDOT and several other road maintenance organizations. WSDOT specifies that corrosion-inhibited chemicals must be at least 70 percent less corrosive than salt. A laboratory test that simulates environmental exposure to snow and ice control chemicals has traditionally been used to verify whether or not chemicals meet this specification. Steel is typically the metal of choice in conducting this lab test. The corrosion-inhibited chemicals generally come close to, meet, or exceed the 70 percent specification when tested on steel using the laboratory analysis. Use of the corrosion-inhibited chemicals in the field evaluation did not meet the 70 percent specification in any comparison scenarios. In some scenarios, the use of corrosion-inhibited chemicals resulted in some reductions in corrosion and in other scenarios, their use resulted in more corrosion compared to the use of salt.

In the environmental evaluation, chloride levels found in roadside soils, surface water, and underlying groundwater were found to be generally low and well below any applicable regulatory standards or guidelines. No pattern was evident from this evaluation of increased contribution of chlorides to the roadside environment dependent on whether salt was used or corrosion-inhibited chemicals were used.

WSDOT is not making any immediate policy changes based on the findings of this evaluation. The findings of this report will be shared with other road maintenance organizations, the snow and ice control chemical manufacturing industry, and other highway maintenance stakeholders. This evaluation will be extended for at least one more winter season to add to the body of knowledge for future policy decisions.

BACKGROUND AND RESEARCH OBJECTIVES: Before the late 1980's, the Washington State Department of Transportation (WSDOT) used sodium chloride in the form of rock salt for the control of snow and ice on highways. Rock salt was used as a supplement to plowing snow and applying abrasives (i.e. sand) onto icy road surfaces. Rock salt was applied to the road surfaces to help melt and breakup compact snow and ice. It was also blended with sand stockpiles to prevent the stockpile from freezing into an unworkable block as well as to add some ice/snow-melting capabilities to traction abrasives. Salt application rates were as high as 800 pounds per lane mile. Additionally, several applications were typically needed if accumulations of snow and ice formed on the roadway before salt was applied.

In the early 1990's, a practice known as anti-icing was becoming more widely utilized by road maintenance organizations. Anti-icing is the practice of applying chemical freeze point depressants to the roadway to prevent the formation of frost or the bonding of snow/ice to the pavement surface. This is commonly achieved by applying a liquid chemical solution to the pavement in advance of a forecast frost or snow weather event. Under many circumstances, anti-icing will provide a safer roadway and be more cost-effective than a traditional plow and sand approach or waiting until snow and ice compacts and bonds to the pavement before chemical treatments are applied.

Many of the snow and ice control chemicals that became available in the late 1980's had corrosion-inhibiting compounds added to them to mitigate the adverse corrosion impacts from the use of chloride-based compounds. While the costs to purchase these corrosion-inhibited chemicals is significantly higher than sodium chloride, these costs would theoretically be outweighed by the savings from reduced corrosion to motor vehicles, bridges, and other metal-containing highway system components.

Amidst legislative and agency concerns over adverse impacts from using non-corrosion-inhibited sodium chloride (hereafter referred to as "sodium chloride", "rock salt", or "salt brine") and the availability of corrosion-inhibited chemicals, WSDOT made a policy decision to discontinue the use of sodium chloride for highway snow and ice control in the late 1980's. Relatively few other road maintenance organizations have completely discontinued the use of sodium chloride for snow and ice control. Many have evaluated alternative snow and ice control chemicals and have incorporated their use to varying extents. In most cases however, sodium chloride continues to be used solely or predominantly used for snow and ice control. This is due to its relatively low price, its utility in helping road maintenance personnel keep roads open during inclement winter weather, its usefulness in providing safe winter driving conditions, improved corrosion protection in the truck and automobile manufacturing industry, acceptance of some levels of corrosion, and doubts about actual reduced corrosion from use of alternative, corrosion-inhibited chemicals.

In the years since this policy change, WSDOT personnel have noticed continued corrosion on maintenance trucks and have received complaints from road users regarding corrosion. On the other hand, WSDOT Bridge personnel have noticed a general decrease in the amount of rehabilitation work needed on bridge decks due to corrosion in the underlying rebar. This conflicting information has caused WSDOT maintenance personnel to raise the question of how much reduction in corrosion is actually occurring in the roadway environment from the use of corrosion-inhibited chemicals compared to the use of salt. The only documentation of relative corrosion rates from exposure to sodium chloride and corrosion-inhibited chemicals under like circumstances has been from tests conducted under controlled, laboratory conditions. It seemed plausible that differences between the controlled laboratory environment and the variable roadway environment might lead to different rates of relative corrosion.

In addition to the questions about corrosion from snow and ice control chemicals, it was felt that an overall evaluation of sodium chloride as a highway maintenance tool in Washington State was needed. Factors that led to this include sodium chloride's cost-effectiveness, changing anti-icing chemical application practices, other road maintenance organizations' extensive, continued use of sodium chloride, and improved corrosion protection practices in the truck and automobile manufacturing industry as well as in bridge construction. The use of liquid anti-icers (i.e. salt brine) in a preventive manner results in much lower levels of chlorides being applied to the roadway. Application of chloride-based liquids typically equates to approximately 100 pounds of salt, or chlorides, per lane mile. Contemporary application rates for solid chemicals (i.e. rocksalt)), when used for accumulated snow or compact snow and ice, are typically between 200 and 300 pounds per lane mile.

<u>Research Objectives:</u> The general objective of this research project was to carry out a multi-faceted comparison of sodium chloride and corrosion-inhibited chemicals under real-world roadway conditions. Specific objectives include:

1. Compare snow and ice control costs of using sodium chloride to like costs using corrosion-inhibited chemicals.

2. Compare the results (i.e. road conditions) of snow and ice control activities carried out by using sodium chloride products to like results from the use of corrosion-inhibited chemicals.

3. Compare corrosion of metal exposed to sodium chloride to metal exposed to corrosion-inhibited chemicals.

4. Compare chloride levels in roadside soils, surface water, and underlying groundwater in areas using sodium chloride to chloride levels in areas using corrosion-inhibited chemicals.

TEST LOCATIONS: WSDOT initially selected two test locations where salt brine and rock salt would be the sole snow and ice control chemicals used. Two other sections were selected where corrosion-inhibited chemicals were the sole snow and ice chemicals used. Plowing and sanding activities were also conducted as needed in both salt and corrosion-inhibited chemical sections.

Salt Sections

1. I-90 from I-82 Interchange (mp111/ARM109.29) to Vantage (mp 136.5/ARM134.79) - SC Region, Maintenance Area 1
2. I-90 from east of Moses Lake (Weber Coulee - mp 191.89/ARM190.18) to Lincoln/Spokane county line (mp 255.29/ARM253.01) - Eastern Region, Maintenance Area 3

Corrosion-inhibited Chemical Sections

1. I-90 from Vantage (mp 136.5/ARM134.79) to east of Moses Lake (Weber Coulee - mp 191.89/ARM190.18) - NC Region, Maintenance Area 2
2. I-90 from Lincoln/Spokane county line (mp 255.29/ARM253.01) to the Idaho border (mp 299.82/ARM297.52) - Eastern Region, Maintenance Area 1

After the initial planning of the pilot project commenced, maintenance personnel from WSDOT's SW region expressed an interest in participating in the project. SR 6 between Chehalis and Raymond was selected as a section for salt use. A specific section of highway on which corrosion-inhibited chemicals were to be applied was not selected in the SW region for the purpose of comparing data with the salt section. Instead, two maintenance trucks that applied corrosion-inhibited chemicals on several highways in the general vicinity of SR 6 were selected for data comparison purposes.

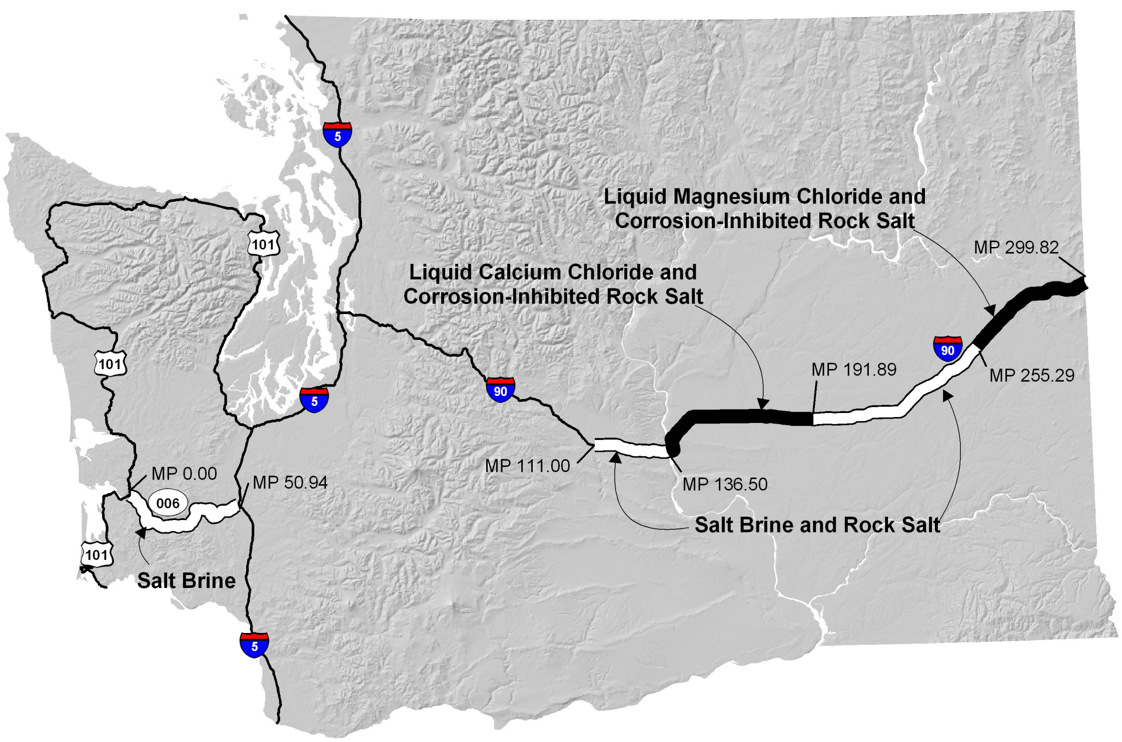

Figure 1: Salt and Corrosion-inhibited Chemical Test Sections

MATERIALS USED: In both of the I-90 salt sections, the liquid anti-icing chemical used was salt brine made by mixing rock salt with water. The brine was mixed to a concentration of 23% sodium chloride, as this is the optimal concentration for effective anti-icing of roadways. The correct sodium chloride concentration was determined by using a salinometer. A Varitech SB600 salt brine maker was purchased and used to produce all salt brine used on the I-90 test sections. Rock salt was also used under certain circumstances. The rock salt used in the pilot project was mined and crushed sodium chloride. The same rock salt used directly on the roadway was used to produce salt brine.

In the NC Region, I-90 corrosion-inhibited chemical section, a corrosion-inhibited, liquid $CaCl_2$ product was used for anti-icing. This material was purchased as a liquid so WSDOT maintenance personnel did not have to perform any mixing or manufacturing of liquid anti-icing chemicals. The solid chemical used in this section was corrosion-inhibited rock salt. In the Eastern Region, Maintenance Area 1, I-90 corrosion-inhibited chemical section, a corrosion-inhibited, liquid, $MgCl_2$ product was used for anti-icing. This material was purchased as a liquid so WSDOT maintenance personnel did not have to perform any mixing or manufacturing of liquid anti-icing chemicals. The solid chemical used in this section was corrosion-inhibited rock salt.

For the SR 6 salt section, salt brine was made by mixing pre-measured amounts of water and rock salt in a liquid storage tank until the salt dissolved into solution. The correct sodium chloride solution was determined by using a hydrometer. The type of salt used to make brine on SR 6 was a solar salt (dehydrated salt water) that was purchased and stored in fifty-pound sacks. No rock salt was applied to SR 6 during this pilot project. In the SW region, the trucks selected for comparison to trucks applying salt brine applied a corrosion-inhibited, liquid, $MgCl_2$ product for anti-icing. No solid chemicals were applied to roadways by these trucks in the SW region.

SNOW AND ICE CONTROL METHODS: All participants in the I-90 pilot project sections agreed to use similar methods of snow and ice control as follows:

1. All lanes of roadway would be anti-iced with liquid chemicals in advance of a forecast frost or snow weather event.
2. If snow began accumulating on the road surface, solid anti-icing chemicals would be applied to prevent compacting and bonding with the pavement.
3. If compact snow and ice formed on the road surface, solid de-icing chemicals would be applied to melt and help break up the snow/ice until bare pavement was regained.
4. If temperatures dropped below the effective use range of chemicals, plowing and/or sanding would be used to provide traction.

On SR 6, liquid salt brine was the only chemical used. Application of salt brine was focused on emphasis areas (i.e. curves, steep grades, intersections) when needed. No solid rock salt was used. Plowing and sanding were to be used as needed.

Liquid anti-icing chemicals were applied to the roadway via either spray trucks or tank trucks. Many of WSDOT's spray trucks are specifically manufactured for herbicide applications during the spring, summer, and fall months but they work very well for applying anti-icing chemicals during the winter. They are equipped with a large tank, motorized pump, computer controls, and spray bars and nozzles for chemical applications. Tank trucks are specifically manufactured for flushing water onto roadways for cleaning or dust control purposes. With minimal alterations, these trucks effectively apply anti-icing chemicals onto the roadway during winter. Solid anti-icing chemicals were applied with dump trucks equipped with hopper/sander units. These trucks were also equipped with pre-wet units so solid anti-icing chemicals could be wetted just before being applied to the roadway for improved adhesion to the road surface and quicker snow/ice melting action.

WINTER WEATHER SEVERITY: Weather conditions affect snow and ice control expenditures and results more than for any other highway maintenance activity. More severe winter weather usually results in higher maintenance expenditures and a reduced ability to keep the highways clear of ice and snow relative to milder winter weather. In reviewing and analyzing maintenance data related to snow and ice, a corresponding measure of winter severity provides a valuable context in which information is considered.

WSDOT utilizes a measure of winter severity known as the Winter Index (WI). The winter index was developed as part of a Strategic Highway Research Project (SHRP H-350) specifically for measurement of winter severity in North America. It is a mathematical calculation that produces a numeric weather severity value by using daily temperatures and snowfall data.

$$\mathbf{WI = -25.58\ [TI]^{1/2} + (-35.68)\ ln((S/10)+1) + (-99.5)\ [(N/(R+10))]^{1/2} + 50}\ *$$

Temperature Index (TI) - 0 if the minimum air temperature is above 32 F; 1 if the maximum air temperature is above 32 F while the minimum air temperature is at or below 32 F; 2 if the maximum air temperature is at or below 32 F. The averaged daily value is used. (Weighted 35%)

Snowfall (S) - The daily amount of snowfall in millimeters. (Weighted 35%)

Number of Air Frosts (N) - mean daily values of days with minimum air temperature at or below 32 F. (Weighted 30%)

Temperature Range (R) - The difference between the mean monthly maximum air temperature and the mean monthly minimum air temperature. (Weighted 30%)

* The four coefficients in this equation tailor the Winter Index to United States climate.

Figure 2; Winter Index Calculation

Since real-time snowfall information is not available to WSDOT, a modification to the Winter Index is used by WSDOT. The same formula, minus snowfall data, is used and this is termed the Frost Index. WSDOT has compared historical Winter Index ratings and Frost Index ratings and has found a very close and consistent correlation between the two. To calculate a Frost Index for the state of Washington, WSDOT uses temperature data from 29 locations that are geographically distributed across the state. Airport temperature information is used, as this is more reliable than information from other, less sophisticated weather information sources. The following chart shows the historical trend in the statewide Frost Index since WSDOT began tracking winter severity. The statewide Frost Index for the winter of 2002-03 shows a winter season throughout Washington State that was milder than average. This was corroborated by discussions with maintenance personnel in various regions who cited reduced winter maintenance expenditures, low amounts of snowfall, and relatively warm temperatures. The relatively mild winter provided conditions that were conducive for anti-icing in general. The warmer temperatures also more often provided conditions where sodium chloride could be effectively used compared to other winters past.

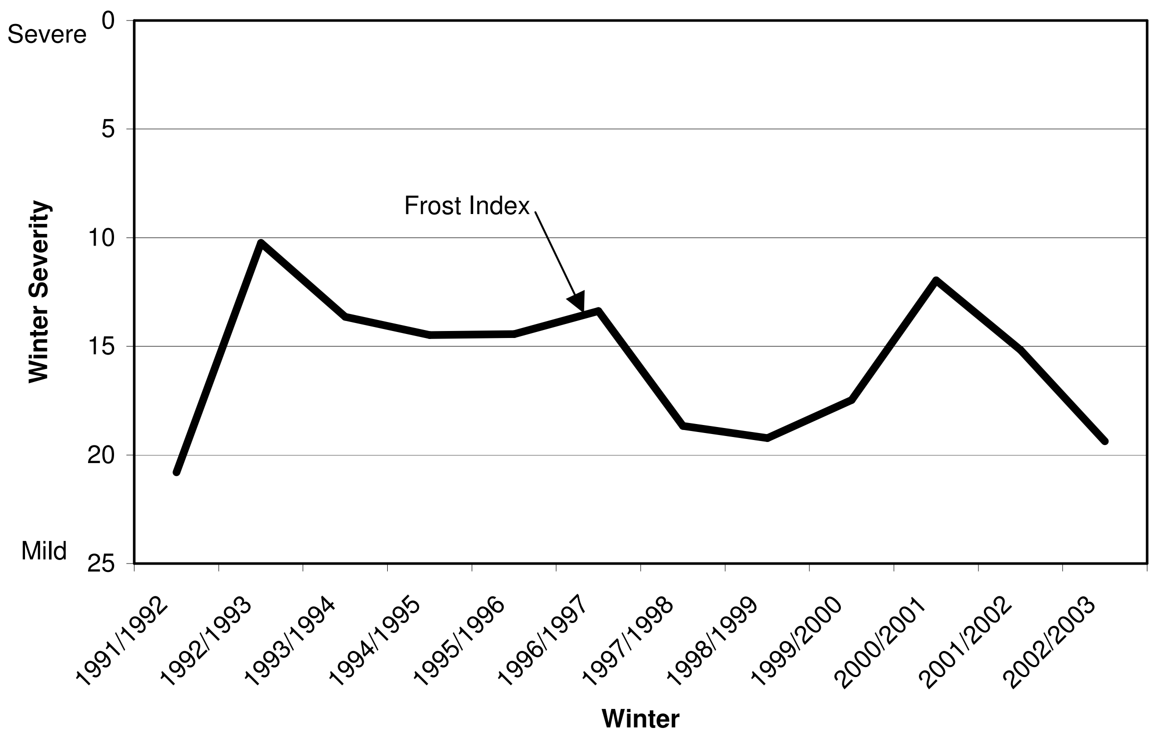

Figure 3: Historical Trend of Winter Severity in Washington State

COSTS: Snow and ice control operational costs incurred during the pilot project were tabulated for each project section. The primary objective of documenting these costs is to be able to generate a general comparison of the operational costs of a maintenance program that is reliant on salt products for snow and ice control to a maintenance program that is reliant on corrosion-inhibited chemical products for snow and ice control. Cost items included in this tabulation are materials, labor, and equipment expenditures.

The capital costs to prepare for the pilot project, such as constructing salt sheds and purchasing a brine maker, were not included for the comparison of costs incurred for controlling snow and ice between different project sections. However, the following detail provides cost information on these items for the sake of background information. Seven storage sheds were constructed for the purposes of storing stockpiles of either rock salt or corrosion-inhibited rock salt. Each shed was 33 feet wide and 48 feet deep and constructed with wood pole frames and a steel roof and steel walls down to about six feet from the ground. An asphalt pad served as the floor of each shed and stacked, concrete, ecology blocks comprised the lower walls up to the bottom of the steel walls. Each shed cost a total of approximately $27,000. The brine maker for the Eastern test area cost $7,500 and its insulated, heated housing structure cost $10,000. One 10,500 gallon, liquid storage tank was purchased for $5,000 to be located in the SC salt section.

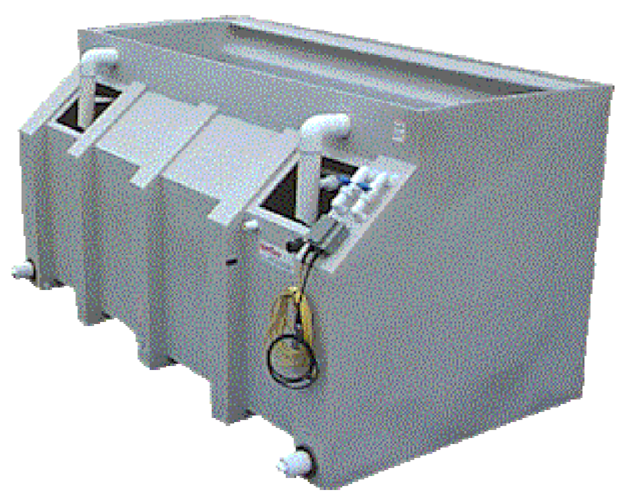

Figure 4: Varitech SB600 Salt Brine Maker

Materials costs are comprised of expenditures to either purchase or make anti-icing chemicals and abrasives that are used for snow and ice control. Transportation costs are not broken out separately as the material costs are for products delivered to WSDOT maintenance facilities. The cost of salt brine has the labor cost to make the salt brine included as part of the material cost. Regarding the compared costs of anti-icing materials used in this evaluation, salt brine and rock salt are significantly less expensive than the alternative, corrosion-inhibited products. If the use of salt brine and rock salt were increased and further integrated into WSDOT winter maintenance activities, their costs would be reduced even further. The WSDOT contract under which rock salt was purchased during the pilot project was hastily developed to accommodate this pilot project. As such, minimal advertising took place and there was little competition for this contract. In subsequent discussions with several salt vendors, they indicated that they had not heard of the opportunity to bid on this contract and would be interested in competing in any future bidding. There were also indications that salt prices, lower than what WSDOT paid during the pilot project, could be obtained through increased advertisement and bidding competition. The manufacturing of salt brine using the purchased brine maker proved to be much more cost-effective than manually making salt brine by mixing salt and water in storage tanks. The purchase and use of additional brine makers would reduce the overall cost of salt brine. The brine makers' relatively low purchase cost is quickly made up in cost savings compared to purchasing pre-made salt brine or corrosion-inhibited liquid anti-icing chemicals.

SALT SECTIONS

LOCATION	PRODUCT	COST PER UNIT*	QUANTITY*	TOTAL COST
SC Region Salt Section	Sand	$11.75	500	$5,875
	Conditioner for sand stockpiles	$74.79	50	$3,740
	Salt Brine	$0.20	48,564	$9,713
	Rock Salt	$74.79	470	$35,151
	Pre-wetting salt brine		0	
Total				**$54,479**
Eastern Region Salt Section	Sand	$9.31	41	$382
	Conditioner for sand stockpiles	$73.82	4	$295
	Salt Brine	$0.12	120,900	$14,508
	Rock Salt	$73.82	674	$49,784
	Pre-wetting salt brine	$0.12	11,801	$1,416
Total				**$66,385**
SW Region Salt Section	Sand		0	
	Salt Brine	$0.27	21,905	$5,914
	Pre-wetting salt brine		0	
Total				**$5,914**

CORROSION-INHIBITED CHEMICAL SECTIONS

LOCATION	PRODUCT	COST PER UNIT*	QUANTITY*	TOTAL COST
NC Region Corrosion-Inhibited Chemical Section	Sand	$10.49	30	$315
	Conditioner for sand stockpiles	$136.80	3	$410
	Liquid Calcium Chloride	$0.55	96,946	$53,320
	Corrosion-inhibited Rock Salt	$136.80	463	$63,356
	Pre-wetting Calcium Chloride	$0.55	180	$99
Total				**$117,501**
Eastern Region Corrosion-inhibited Chemical Section	Sand	$7.06	1,500	$10,590
	Conditioner for sand stockpiles	$141.36	150	$21,204
	Liquid Magnesium Chloride	$0.35	200,000	$70,000
	Corrosion-inhibited Rock Salt	$141.36	1,240	$175,286
	Pre-wetting Magnesium Chloride	$0.35	27,400	$9,590
Total				**$286,670**
SW Region Corrosion-unhibited Chemicals	Liquid Magnesium Chloride	$0.40		

* Abrasives are reported in cubic yards
* Solid chemicals reported in tons
* Liquids are reported in gallons

Figure 5: Salt Pilot Project Materials Costs

Equipment costs are comprised of truck use-time expenditures. All trucks used for snow and ice control activities in the pilot project are owned by WSDOT. WSDOT has a revolving fund for trucks and other equipment in which use rates are paid into a fund that ensures replacement of the truck or equipment at the end of its useful life. Non-use rates also contribute to the fund for replacement but only use rates are utilized for the purposes of this project's cost comparison component.

Labor costs are comprised of the wages and benefits paid to highway maintenance workers who carried out snow and ice control activities on test and control sections. Labor expenditures are typically for operating either a truck that plows snow and/or applies abrasives, solid chemicals, or liquid chemicals.

SALT SECTIONS

Location	Equip #	Hours	Hourly Equip. Rate	Total Equip. Expenditure	Hourly Labor Rate	Total Labor Expenditure
SC Region Salt Section	8E12-9	214	$10.85	$2,316.48	$24.95	$5,326.83
	6E13-1	206	$11.72	$2,414.32	$24.95	$5,139.70
Total		420		$4,730.80		$10,466.53
Eastern Region Salt Section	6G13-44	206	$11.72	$2,414.32	$24.95	$5,139.70
	8G13-02	218	$10.89	$2,374.02	$24.95	$5,439.10
	6B13-43	159	$11.72	$1,863.48	$24.95	$3,967.05
	6G13-70	123	$11.72	$1,441.56	$24.95	$3,068.85
	6G6-95	38	$10.76	$408.88	$24.95	$948.10
	6G13-84	26	$11.72	$304.72	$24.95	$648.70
	6G13-47	128	$11.72	$1,500.16	$24.95	$3,193.60
	6G13-38	197	$11.72	$2,308.84	$24.95	$4,915.15
	8G29-2	111	$11.44	$1,269.84	$24.95	$2,769.45
Total		1206		$13,885.82		$30,089.70
SW Region Salt Section	6D6-95	102	$10.76	$1,097.52	$24.95	$2,544.90
	8D29-4	60	$11.44	$686.40	$24.95	$1,497.00
Total		162		$1,783.92		$4,041.90

CORROSION-INHIBITED CHEMICALS SECTIONS

Location	Equip #	Hours	Hourly Equip. Rate	Total Equip. Expenditure	Hourly Labor Rate	Total Labor Expenditure
NC Region Corrosion-inhibited Chemical Section						
Total *				$12,564.00		$24,347.00
Eastern Region Corrosion-inhibited Chemical Section	8B12-8	256	$10.85	$2,777.60	$24.95	$6,387.20
	6G13-39	170	$11.72	$1,992.40	$24.95	$4,241.50
	6G6-3	83	$10.76	$893.08	$24.95	$2,070.85
	6G13-71	233	$11.72	$2,730.76	$24.95	$5,813.35
	6G13-79	87	$11.72	$1,019.64	$24.95	$2,170.65
	6G13-40	164	$11.72	$1,922.08	$24.95	$4,091.80
	6G13-63	162	$11.72	$1,898.64	$24.95	$4,041.90
	8G12-11	97	$10.85	$1,052.45	$24.95	$2,420.15
	6G13-76	239	$11.72	$2,801.08	$24.95	$5,963.05
	8G12-7	172	$10.85	$1,866.20	$24.95	$4,291.40
Total		1663		$18,953.93		$41,491.85
SW Region Corrosion-inhibited Chemicals	6D13-34	101	$11.72	$1,183.72	$24.95	$2,519.95
	8D29-2	96	$11.44	$1,098.24	$24.95	$2,395.20
Total		197		$2,281.96		$4,915.15

* NC control section costs were tracked based on the entire section of roadway as opposed to individual pieces of equipment

Figure 6: Salt Pilot Project Equipment and Labor Costs

Several variables must be considered when assessing the costs of delivering a winter maintenance program. An example of this is in regards to costs per unit and application rates of anti-icing chemicals. Unit costs vary but so do required application rates. While the unit cost of a certain chemical may only be half of another chemical, the total costs may actually be more if the chemical has to be applied at a much higher rate. Another example is related to the roadway area of responsibility. Total monetary costs between two sections may be similar, but significant differences in miles of roadway maintained will provide important information about program efficiency. A simple way to improve the "fairness" of cost comparisons is to put total costs into terms of costs per lane mile over an entire winter season. While this doesn't factor in every possible variable, it does provide a generally good medium of comparison.

Location	Labor	Equipment	Materials	Lane Miles	$/Lane Mile
SC Region Salt	$10,467	$4,731	$54,479	102	**$683.10**
NC Region Corrosion-inhibited Chemicals	$24,347	$12,564	$117,501	222	**$695.55**
Eastern Region Salt	$30,090	$13,886	$66,385	253	**$436.21**
Eastern Region Corrosion-inhibited Chemicals Control	$41,492	$18,954	$286,670	210	**$1,652.93**
SW Region Salt	$4,042	$1,784	$5,914	103	**$113.98**

Figure 7: Salt Pilot Project Costs per Lane Mile

SNOW AND ICE CONTROL RESULTS/PERFORMANCE: WSDOT measures performance for a variety of maintenance activities using a program known as the Maintenance Accountability Process (MAP). Performance measures are focused on customer-oriented outcomes, or the results of maintenance work with which highway users can identify. Results are typically determined by field evaluations that assess the condition of highway system features. Results are identified in terms of Level of Service (LOS). LOS is communicated in terms of a letter-grade scale similar to school report cards. A LOS of "A" is the best LOS and a LOS of "F" is the poorest LOS.

Throughout the winter season, periodic field evaluations are conducted on randomly-selected segments of highway to assess winter driving conditions. Evaluations are conducted only when conditions producing frost, snow, or ice on the highway are present. These are the conditions that necessitate WSDOT actions (i.e. applying anti-icing chemicals, sand, or plowing snow) to provide for safety and motorist mobility. The condition of the roadway segment is rated on how much bare pavement is provided by anti-icing chemicals or how much sand is present for enhanced traction. Since bare pavement provides better traction than a sanded, icy road surface, a bare pavement outcome will be rated as a higher LOS. A roadway that is maintained in a bare condition will generally be rated as an "A" LOS. A roadway that is maintained as an icy or compact snow and ice surface with abrasives applied on top will generally be rated as a "C" LOS. An icy or compact snow/ice road surface with no abrasives on it will generally be rated as an "F" LOS. Some variations will occur in the LOS ratings dependent on whether or not certain conditions are consistently present on the road or only present on portions of the road. Rating information from each survey is accumulated over a season and the average rating is what determines the LOS delivered over the winter season.

Several roadway segments within the project sections were utilized for field evaluations and LOS calculation. A summary of the LOS ratings for each project section is shown below. The LOS rating for each section represents the average condition in which the subject roadway was maintained during the winter season.

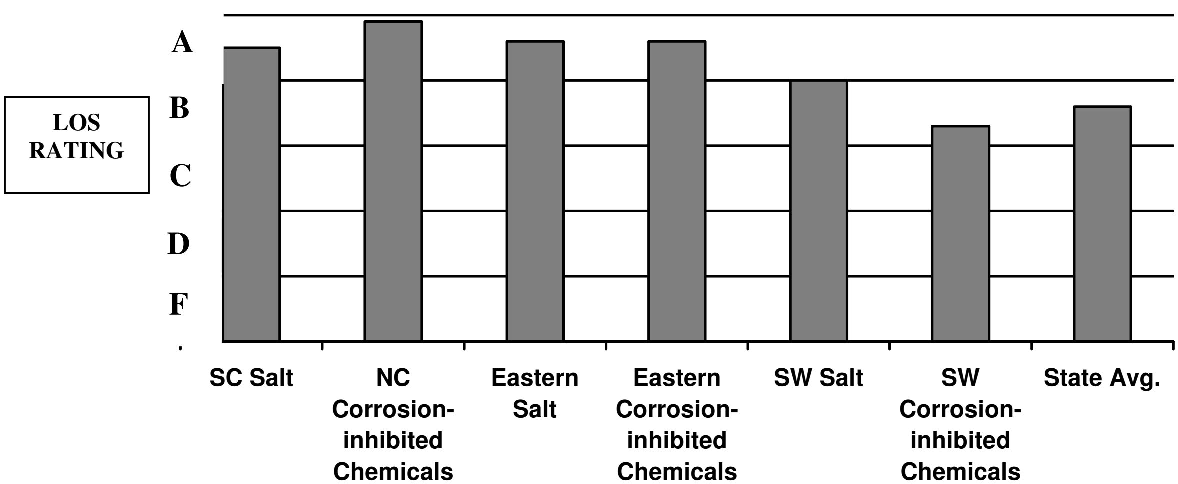

Figure 8: Level of Service Ratings for Project Test Sections

Overall, a high LOS was delivered in all of the project sections. The frequent use of chemicals for snow and ice control and the relatively mild winter were contributing factors to this. The small differences in LOS ratings between sections in the SC, NC, and Eastern regions are most likely not going to be noticed by the average highway user. The lower LOS in the SW salt section reflects a slightly different approach to anti-icing compared to the other project sections on I-90. The SW region focuses anti-icing activities on emphasis areas (i.e. curves, grades, shaded areas) while the other regions anti-ice entire stretches of highway. The lower LOS on SW region highways where corrosion-inhibited chemicals were used compared to the SW test is due to less chemical use because of higher costs relative to salt brine. The higher LOS in the NC region is most likely attributable to more years of experience using anti-icing chemicals. Personnel in the NC region have been using anti-icing chemicals longer than their counterparts in other WSDOT regions. A more detailed table of the LOS data can be found in Appendix 1.

While the measured results of roads treated with sodium chloride compared to roads treated with corrosion-inhibited chemicals is important, other performance factors are relevant and should be reported. In terms of general effectiveness, maintenance personnel found that salt brine was equivalent to corrosion-inhibited chemicals in its ability to prevent frost from forming on pavement surfaces and to prevent snow and ice from bonding to the pavement surface. This is only under the temperature range (approximately 20 degrees or warmer) in which salt should be used. In colder conditions, the effectiveness of salt brine will diminish while other chemicals will continue to work. The dried residual from salt brine applied to the pavement surface was generally found to retain its effectiveness in preventing frost formation or bonding of snow/ice to pavement for one day less than the corrosion-inhibited $MgCl_2$ and $CaCl_2$ products used in control sections. No significant differences were noted between rock salt and the corrosion-inhibited rock salt in their snow/ice melting performance on roadways in project sections.

Regarding handling and working with the liquid anti-icers, maintenance crews found salt brine to be more favorable than the corrosion-inhibited products. One of the reasons is that once the salt brine was made to the correct concentration, the salt would stay in solution during storage without having to be circulated or agitated. The corrosion-inhibited chemicals need to be circulated or agitated while in storage to prevent solids from settling out and diminishing the effectiveness of the remaining liquid product. In regards to washing maintenance trucks and equipment, maintenance crews found the salt brine much easier to wash off than the corrosion-inhibited chemicals. The corrosion inhibited chemicals are sticky and take more effort to wash from trucks and equipment.

Another performance-related issue is chemical slipperiness. This can occur under certain conditions as a liquid anti-icer dehydrates and rehydrates on the pavement surface. During the dehydration/rehydration phase, the chemical can turn into a slippery slurry form as it transitions from a dry form to a wet form or vice versa. During this past winter, WSDOT experienced a few instances that appeared to be chemical slipperiness where corrosion-inhibited anti-icers had been used. While these instances were not specifically within any sections of this pilot project, they are still noteworthy in a general comparison of salt brine to other corrosion-inhibited chemicals. Salt brine is generally regarded as less prone to chemical slipperiness than commonly-used corrosion-inhibited chemicals. No instances of chemical slipperiness were noted in sections where salt brine was used during the pilot project.

CORROSION STANDARDS: WSDOT is a member of a consortium of northwest state DOT's and Canadian provinces known as the Pacific Northwest Snowfighters (PNS). One of PNS's functions is to develop anti-icing chemical specifications that all member organizations utilize. This helps to standardize the market for anti-icing chemicals thus obtaining better pricing and product availability for road maintenance organizations. The PNS specification for corrosion is that a corrosion-inhibited anti-icing chemical must be at least 70% less corrosive to a given type of metal than sodium chloride is corrosive to that same type of metal. This reduced level of corrosion is determined by a laboratory test.

Generally, the lab test consists of immersing and removing separate metal washers into a sodium chloride solution and a corrosion-inhibited chemical solution. Over a 72-hour period, the metal samples are immersed for fifty minutes and removed from the solution for ten minutes. This immersion/removal is done hourly for the 72-hour period. After the test period is complete, the metal samples are weighed. If the metal sample exposed to corrosion-inhibited chemicals has at least 70% less weight loss compared to the weight loss of the metal sample exposed to the sodium chloride solution, the corrosion-inhibited chemical meets the PNS specification. The detailed procedure for this test is explained in Appendix 2.

MEASURING CORROSION IN THE ROADWAY ENVIRONMENT: The field replication of the laboratory corrosion analysis consisted of attaching samples of metal to WSDOT maintenance trucks working on highways where the only anti-icing chemical they would be exposed to is sodium chloride. Similar metal samples were attached to WSDOT maintenance trucks working on highways where the only anti-icing chemical they would be exposed to is a corrosion-inhibited product. Selected trucks were assigned to specific routes for winter maintenance to ensure that they would only be exposed to either type of anti-icing chemical. While the laboratory test uses metal washers, larger pieces of metal were used for the roadway corrosion test. With longer exposure times and more potential corrosion, it was felt that the smaller washers would be inappropriate for this use. The pieces of metal used are approximately four inches by six inches in dimension and are called coupons. Three types of metal were selected based on their common use in the automobile and truck manufacturing industry. Mild steel was selected due to its common use on a wide variety of motor vehicle components. A sheet aluminum alloy (type #5182) was selected due to its use in a variety of car and truck body panels. A cast aluminum alloy (type # A356) was selected due to its use in housings (i.e. transmission housings) of certain car and truck parts.

Each coupon was cleaned, prepared, and weighed. Two coupons of each of the three types of metal were attached to a rack that was in turn attached to WSDOT maintenance trucks. The racks were made of galvanized and painted steel. Coupons were attached to the rack with stainless steel nuts and bolts. Each rack (with mounted coupons) was then mounted on a truck that was used to conduct snow and ice control activities on the project sections. The coupon racks were fitted between the truck chassis rails above the truck's differential. The coupons and rack were marked for tracking purposes. Racks and coupons were fitted to 31 maintenance trucks for this evaluation. These were either dump trucks that applied solid chemicals and/or sand or spray trucks or tank trucks that applied liquid chemicals.

Coupons and racks were also fitted onto four supervisor pickup trucks for a similar evaluation. Supervisor trucks are driven on a variety of highways in the course of daily work. In the evaluation, supervisor trucks in the test areas would be driven on highways where they would be exposed to both sodium chloride as well as corrosion-inhibited chemicals. Supervisor trucks in the corrosion-inhibited chemical sections would be driven on highways where they would be exposed only to corrosion-inhibited chemicals since no salt was used anywhere in these maintenance areas.

One set (steel, sheet aluminum, cast aluminum) of coupons was also fitted onto guardrail posts at select locations in each of the project sections. While they do not have the extensive exposure to anti-icing chemicals that WSDOT maintenance trucks have, they have some exposure from stormwater "splash" by vehicles driving on the highways. The guardrail along the project sections of I-90 is typically ten feet from the nearest travel lane. SR 6 does not have a similar, wide paved shoulder. At the location where the coupons were attached to the guardrail, they were seven feet from the nearest travel lane.

One set of coupons was also fitted onto fence posts at locations remote to the highway in project sections. These locations had no exposure to anti-icing chemicals on the highway and served to measure "background" corrosion levels from exposure to weather. In project sections on I-90, coupons were attached to fence posts at the back edges of highway rest areas. For SR 6, one set of coupons was attached to a fencepost at a pit site 200 feet off the highway and at another location 150 feet off the highway.

A total of 219 coupons were used in the evaluation. After March of 2003, all coupons were removed from trucks, guardrail posts, and other locations and sent to the WSDOT Materials Laboratory for completion of the corrosion evaluation. At the lab, all coupons were cleaned, immersed in an acid bath to remove any corrosion, then weighed to determine weight loss from corrosion.

CORROSION RESULTS: Due to the number of coupons used in the corrosion evaluation, average weight loss amounts were calculated using all coupons of each metal type from each project section. The charts separate corrosion based on the type of metal coupon evaluated. The respective magnitudes of corrosion are significantly different. Weight loss in the steel coupons was on the order of grams. Weight loss in the sheet aluminum and cast aluminum coupons was much less; on the order of tenths of grams. The charts and narrative for the eastern and western Washington components of the pilot project are reported separately due to the differences in winter weather and snow and ice control methodology. More detailed corrosion information is contained in Appendix 3.

<u>Interpreting Corrosion Results:</u> To be included on a WSDOT contract, an anti-icing chemical vendor must submit samples of their anti-icing chemical and it must pass the corrosion-inhibition test (at least 70% less corrosive than sodium chloride, corrosion being measured in weight loss) as well as tests for other impurities such as heavy metals. After a product/vendor is included in a WSDOT anti-icer contract, samples are periodically taken out of shipments to verify whether or not the product is continuing to meet the required specifications throughout the winter season. Verification is determined through the use of the standard laboratory test for corrosion. During the winter of 2002-03, specification compliance analysis showed some problems in this area.

The liquid $MgCl_2$ product used in the Eastern Region met the corrosion specification only six times out of 61 lab tests throughout the winter. The testing also indicated that the $MgCl_2$ was on average, 64% less corrosive than sodium chloride. The liquid $CaCl_2$ product used in the North Central Region met the corrosion specification 13 times out of

13 lab tests throughout the winter. The testing also indicated that the $CaCl_2$ was on average, 81% less corrosive than sodium chloride. The solid, corrosion-inhibited sodium chloride product used in both the Eastern and North Central Regions met the corrosion specification 14 times out of 28 lab tests throughout the winter. The testing also indicated that the solid, corrosion-inhibited sodium chloride was on average, 68% less corrosive than “plain” sodium chloride. The liquid $MgCl_2$ product used in the Southwest Region met the corrosion specification five times out of 20 lab tests throughout the winter. The testing also indicated that the $MgCl_2$ was on average, 65% less corrosive than sodium chloride.

The charts used to depict corrosion rates compare amounts of corrosion in metal samples exposed to corrosion-inhibited chemicals to amounts of corrosion in metal samples exposed to sodium chloride. The target level of reduced corrosion (70% less than salt) is also shown on each measure for corrosion-inhibited chemicals. This way, the reader learns of the “target” and “actual” rates of corrosion. A sample chart that explains how the charts are interpreted follows:

1. The first comparison (two columns on the left side of the chart) shows corrosion weight loss in coupons attached to maintenance trucks. The coupons that were exposed to salt had an average weight loss from corrosion of 10 grams per coupon as shown in the first column. The PNS target specification of 70% less corrosion than salt means that the target level of corrosion from use of corrosion-inhibited chemicals is 3 grams of weight loss from corrosion (70% of 10 grams equals 7 grams: 10 grams minus 7 grams equals 3 grams). The PNS target is identified by the thick, black bar above the second column. The second column represents the measured weight loss from corrosion in the coupons exposed to corrosion-inhibited chemicals. In this case, the corrosion-inhibited chemicals performed better than expected as they caused less corrosion than the PNS target.

2. The second comparison (middle two columns in chart) shows corrosion weight loss in coupons attached to supervisor trucks. Since the weight loss from corrosion in the coupons exposed to salt is 8 grams, the PNS target specification is 2.4 grams (70% of 8 grams is 5.6 grams; 8 grams minus 5.6 grams equals 2.4 grams). In this case, the corrosion-inhibited chemicals met the specification as their use resulted in the same amount of corrosion as specified by the PNS target.

3. The third comparison (two columns on the right side of the chart) shows corrosion weight loss in coupons attached to guardrail. Since the weight loss from corrosion in the coupons exposed to salt is 11 grams, the PNS target specification is 3.3 grams (70% of 11 grams is 7.7 grams; 11 grams minus 7.7 grams equals 3.3 grams). In this case, the corrosion-inhibited chemicals failed to meet the specification as their use resulted in more corrosion than specified by the PNS target.

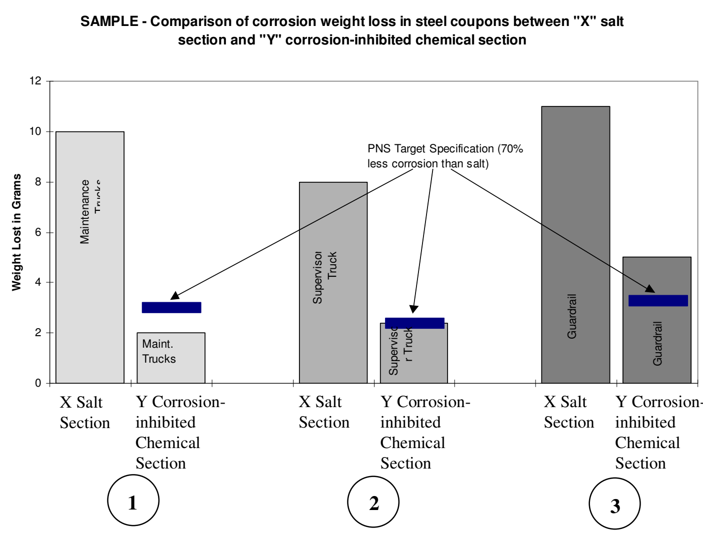

Figure 9: Sample Corrosion Chart

CORROSION COMPARISON – SC REGION SALT AND NC REGION CORROSION-INHIBITED CHEMICALS: Comparisons of corrosion weight loss from sodium chloride exposure to corrosion weight loss from corrosion-inhibited chemical exposure are made between the SC salt section and the NC corrosion-inhibited chemical section as well as between the Eastern Region salt and corrosion-inhibited chemical sections. SC and NC are geographically adjacent to each other and each had coupons from two maintenance trucks. The two Eastern region sections are adjacent and the salt section had coupons on nine trucks and the corrosion – inhibited chemical section had coupons on ten trucks.

The following chart shows corrosion in steel coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the SC salt and the NC corrosion-inhibited chemical sections. The maintenance truck-mounted coupons exposed to corrosion-inhibited chemicals had 53% less corrosion than similar coupons exposed to salt. The supervisor truck-mounted coupons exposed to corrosion-inhibited chemicals had 60% less corrosion than similar coupons exposed to salt. The guardrail-mounted coupons exposed to corrosion-inhibited chemicals had 17% *more* corrosion than similar coupons exposed to salt.

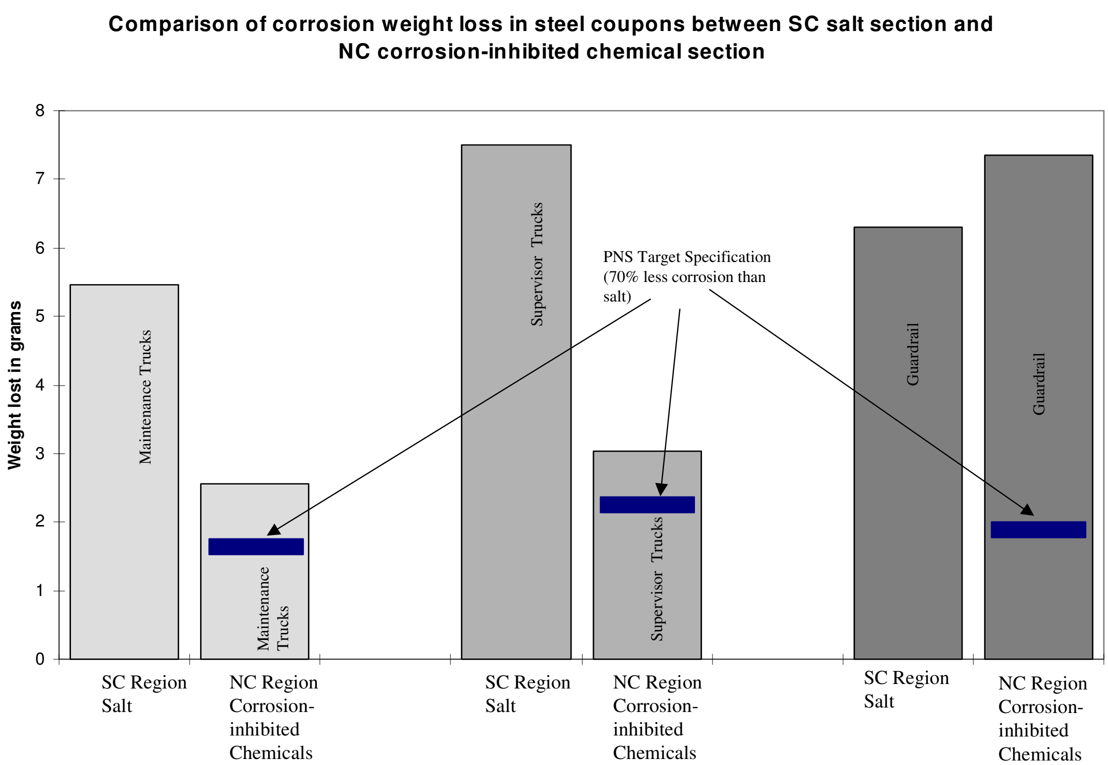

Figure 10: Steel coupon corrosion in SC and NC Region test sections

The following chart shows corrosion in sheet aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the SC salt and the NC corrosion-inhibited chemical sections. The maintenance truck-mounted coupons exposed to corrosion-inhibited chemicals had 180% *more* corrosion than similar coupons exposed to salt. The supervisor truck-mounted coupons exposed to corrosion-inhibited chemicals had 13% *more* corrosion than similar coupons exposed to salt. The guardrail-mounted coupons exposed to corrosion-inhibited chemicals had 100% *more* corrosion than similar coupons exposed to salt.

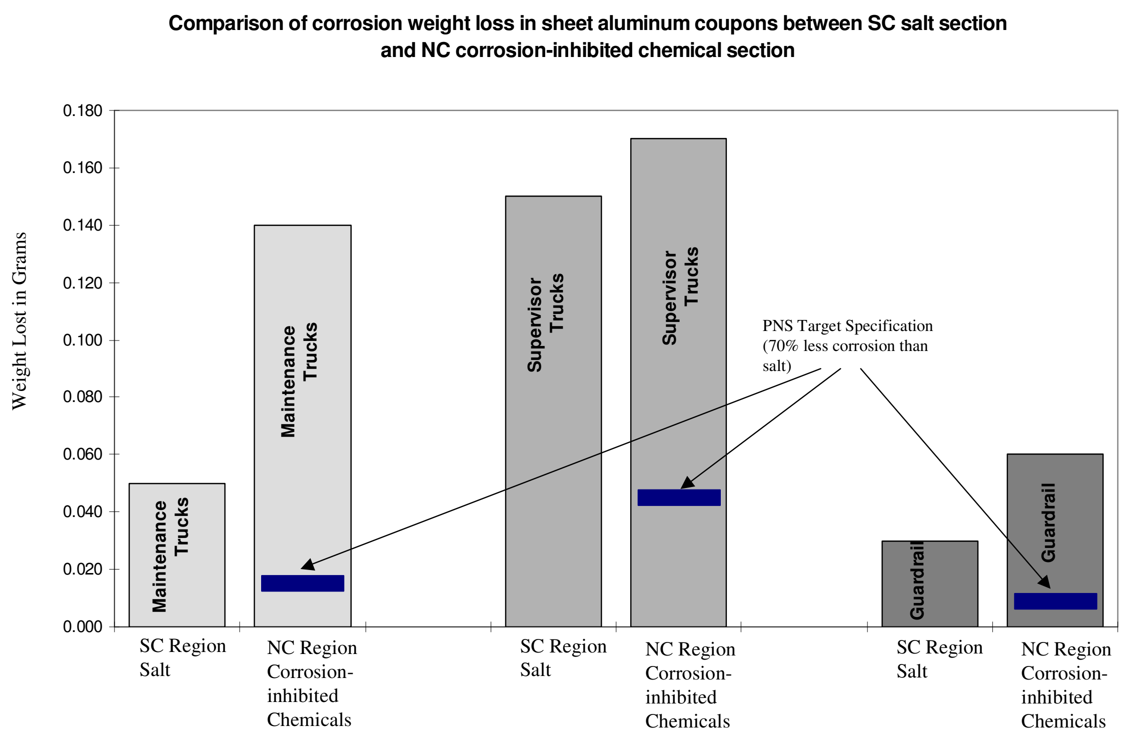

Figure 11: Sheet Aluminum coupon corrosion in SC and NC Region test sections

The following chart shows corrosion in cast aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the SC salt and the NC corrosion-inhibited chemical sections. The maintenance truck-mounted coupons exposed to corrosion-inhibited chemicals had 25% less corrosion than similar coupons exposed to salt. The supervisor truck-mounted coupons exposed to corrosion-inhibited chemicals had 32% less corrosion than similar coupons exposed to salt. The guardrail-mounted coupons exposed to corrosion-inhibited chemicals had 143% *more* corrosion than similar coupons exposed to salt.

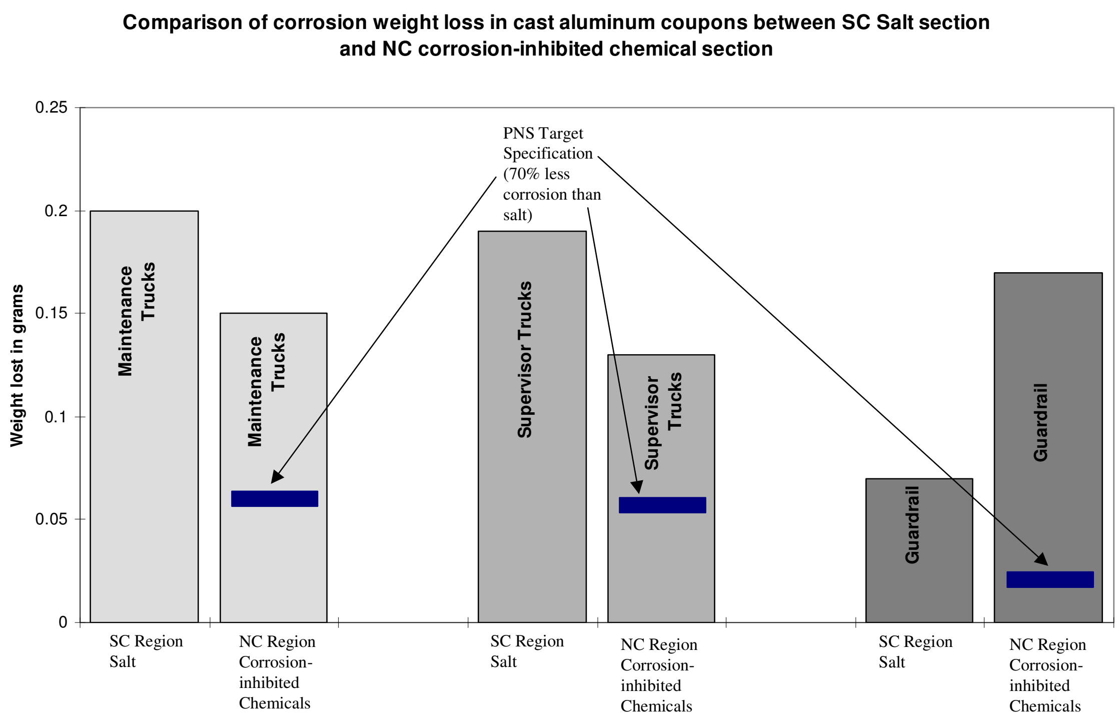

Figure 12: Cast Aluminum coupon corrosion in SC and NC Region test sections

CORROSION COMPARISON – EASTERN REGION SALT AND CORROSION-INHIBITED CHEMICALS: The nex chart shows corrosion in steel coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the Eastern Region salt and corrosion-inhibited chemical sections. The maintenance truck-mounted coupons exposed to corrosion-inhibited chemicals had 30% less corrosion than similar coupons exposed to salt. The supervisor truck-mounted coupons exposed to corrosion-inhibited chemicals had 27% less corrosion than similar coupons exposed to salt. The guardrail-mounted coupons exposed to corrosion-inhibited chemicals had 9% *more* corrosion than similar coupons exposed to salt.

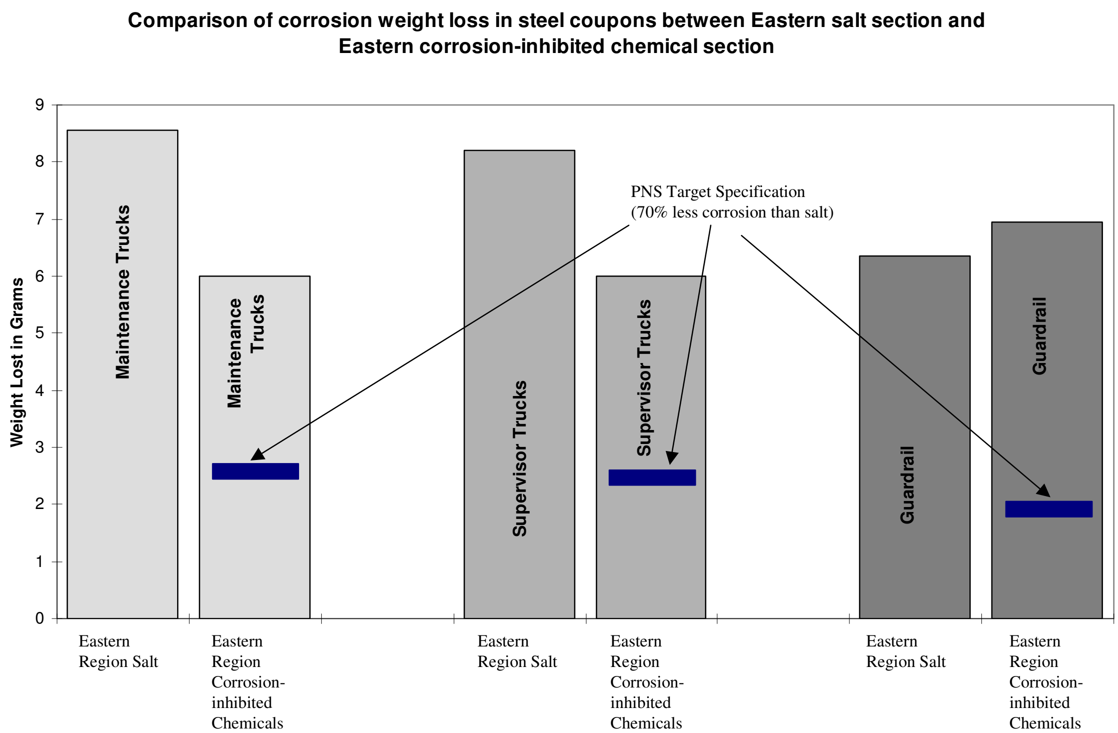

Figure 13: Steel coupon corrosion in Eastern Region test sections

The following chart shows corrosion in sheet aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the Eastern Region salt and corrosion-inhibited chemical sections. The maintenance truck-mounted coupons exposed to corrosion-inhibited chemicals had 140% *more* corrosion than similar coupons exposed to salt. The supervisor truck-mounted coupons exposed to corrosion-inhibited chemicals had 162% *more* corrosion than similar coupons exposed to salt. The guardrail-mounted coupons exposed to corrosion-inhibited chemicals had 50% less corrosion than similar coupons exposed to salt.

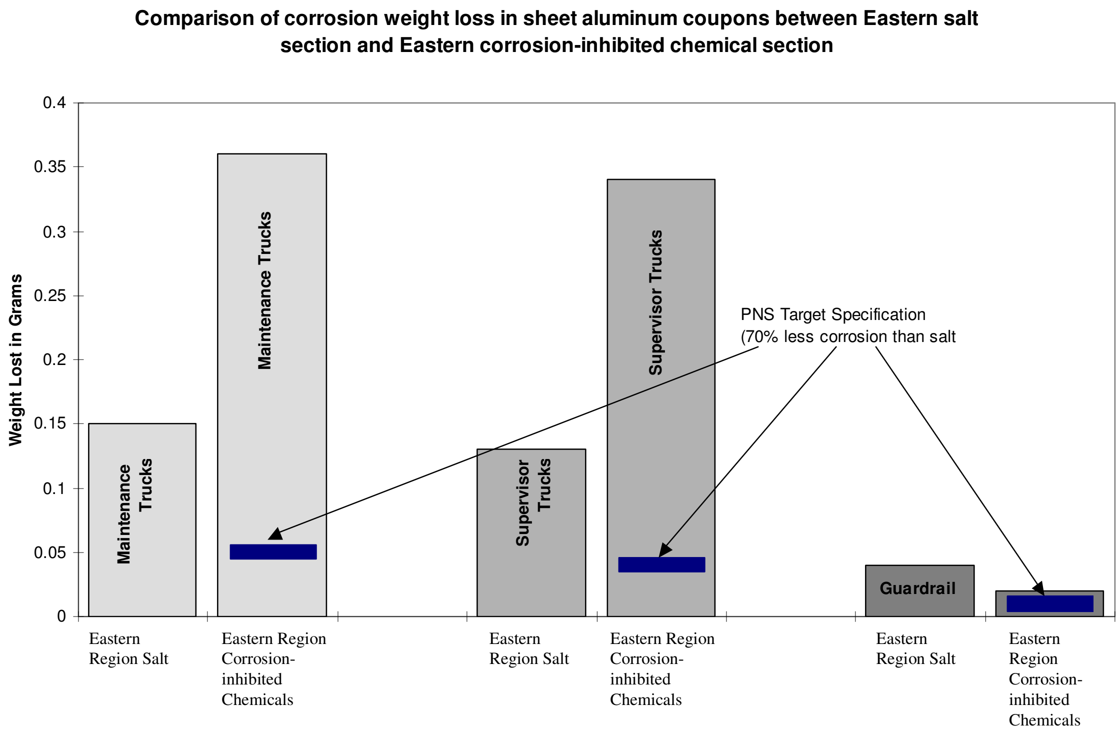

Figure 14: Sheet aluminum coupon corrosion in Eastern Region test sections

The following chart shows corrosion in cast aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the Eastern Region salt and corrosion-inhibited chemical sections. The maintenance truck-mounted coupons exposed to corrosion-inhibited chemicals had 14% *more* corrosion than similar coupons exposed to salt. The supervisor truck-mounted coupons exposed to corrosion-inhibited chemicals had 53% *more* corrosion than similar coupons exposed to salt. The guardrail-mounted coupons exposed to corrosion-inhibited chemicals had 47% less corrosion than similar coupons exposed to salt.

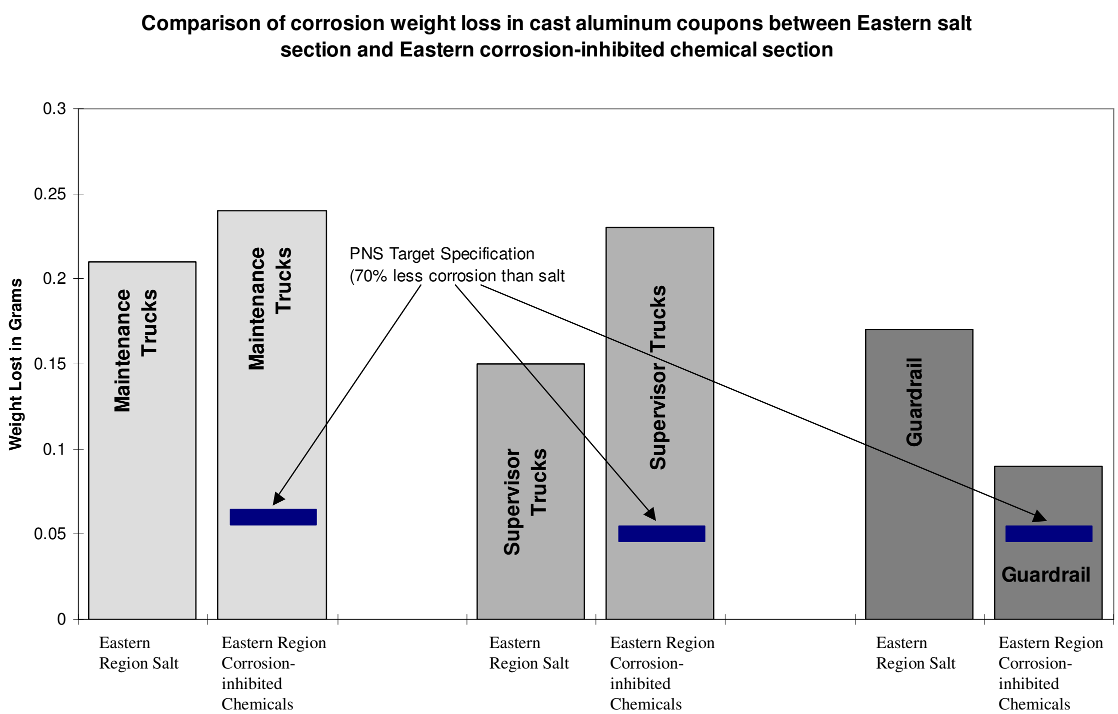

Figure 15: Cast aluminum coupon corrosion in Eastern Region test sections

<u>Discussion:</u> WSDOT maintenance trucks have more intensive exposure to anti-icing chemicals than other motor vehicles on the highways. Maintenance trucks carry loads of the chemicals, they are used to apply the chemicals, and they are driven the highways where chemicals can be applied several times per day. For these reasons, maintenance trucks could be viewed as the "worst case scenario" in evaluating corrosion caused by anti-icing chemicals. The majority of the corrosion coupons used in this evaluation were placed on maintenance trucks.

The steel coupons that were attached to maintenance trucks indicate that corrosion-inhibited chemicals provided some reductions (53% and 30%) to corrosion rates compared to corrosion rates of sodium chloride. These reductions fell short of comparable results from laboratory corrosion analysis as well as the PNS corrosion specification. Of the two corrosion-inhibited liquid chemicals used in the corrosion-inhibited chemical sections, the section using the liquid, calcium chloride product showed better corrosion reduction than the section using the liquid magnesium chloride product in both lab analysis as well as corrosion in the truck-mounted, steel coupons.

In most cases with both types of aluminum coupons that were attached to maintenance trucks, the corrosion rates from exposure to corrosion-inhibited chemicals were actually higher than in exposure to sodium chloride. Once again, the actual corrosion rates were significantly different from the PNS corrosion specification. The PNS corrosion specification and accompanying laboratory test were developed with corrosion to steel in mind. The information on the sheet and cast aluminum coupons indicates that the PNS specification has little to no relevance to actual corrosion of aluminum.

The supervisor pickup truck represents a lesser degree of exposure to anti-icing chemicals than does the maintenance truck. On average, the supervisor pickup truck is driven on highways once or twice per day as the supervisor inspects highway features, checks on maintenance operations and completed work, and otherwise oversees the daily maintenance and operations of the highway. In terms of exposure to corrosion, the supervisor pickup truck is closer to the citizen motor vehicle that is used on the highway for a daily work commute.

Both the steel and aluminum coupons mounted on the supervisor pickup trucks showed similar corrosion rates, as did those coupons from the maintenance trucks. For steel coupons, corrosion in the corrosion-inhibited control sections was less than that in the salt sections but far short of the PNS specification level. For the aluminum coupons, corrosion in the corrosion-inhibited chemical sections was either in excess or slightly less than in the salt sections and fell far short of the PNS specification level.

Coupons mounted on guardrail posts have a less intensive type of exposure than do coupons mounted on maintenance trucks or supervisor pickup trucks. These coupons are exposed to anti-icing chemicals through splash from traffic, some occasional snow or slush that is cast off the highway by a snowplow, and water/chemical that is turned into a mist or fog by traffic action. While the corrosion-inhibited chemicals resulted in some levels of reduced corrosion to steel coupons on maintenance and supervisor trucks, this was not the case with steel coupons mounted on guardrail posts. There was more corrosion on guardrail-mounted steel coupons exposed to corrosion-inhibited chemicals than those exposed to salt. Additionally, the total amount of corrosion on these coupons was greater than the total amount of corrosion on the truck-mounted coupons. While the reasons for this are unknown, it does raise the question of whether or not corrosion inhibitors are providing any actual corrosion reduction in bridges. If corrosion rates associated with corrosion-inhibited chemicals increase as they migrate ten feet from where they are applied to the roadway, will they also increase as the chemicals migrate into bridge decks through pavement cracks or drip down onto structural components of the bridge below the bridge deck? This corrosion information indicates that the PNS specification and accompanying laboratory procedure lack a direct and predictable relationship to corrosion rates that actually occur in the roadway and roadside environment.

CORROSION COMPARISON – SW REGION SALT AND CORROSION-INHIBITED CHEMICALS: In the comparison of corrosion in steel coupons mounted on SW region salt and $MgCl_2$ maintenance trucks, the coupons exposed to $MgCl_2$ had 19% less corrosion than similar coupons exposed to salt.

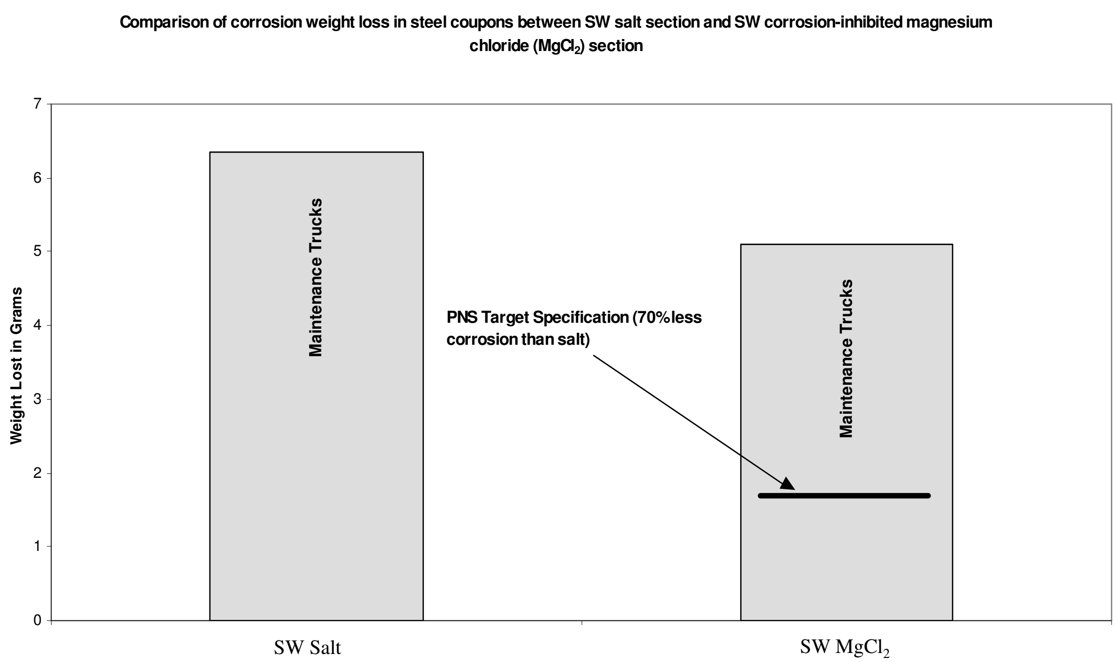

Figure 16: Steel coupon corrosion in Southwest Region test sections

The next comparison shows the average weight loss of sheet aluminum coupons mounted on SW salt and $MgCl_2$ maintenance trucks. The coupons exposed to $MgCl_2$ had 56% *more* corrosion than similar coupons exposed to salt.

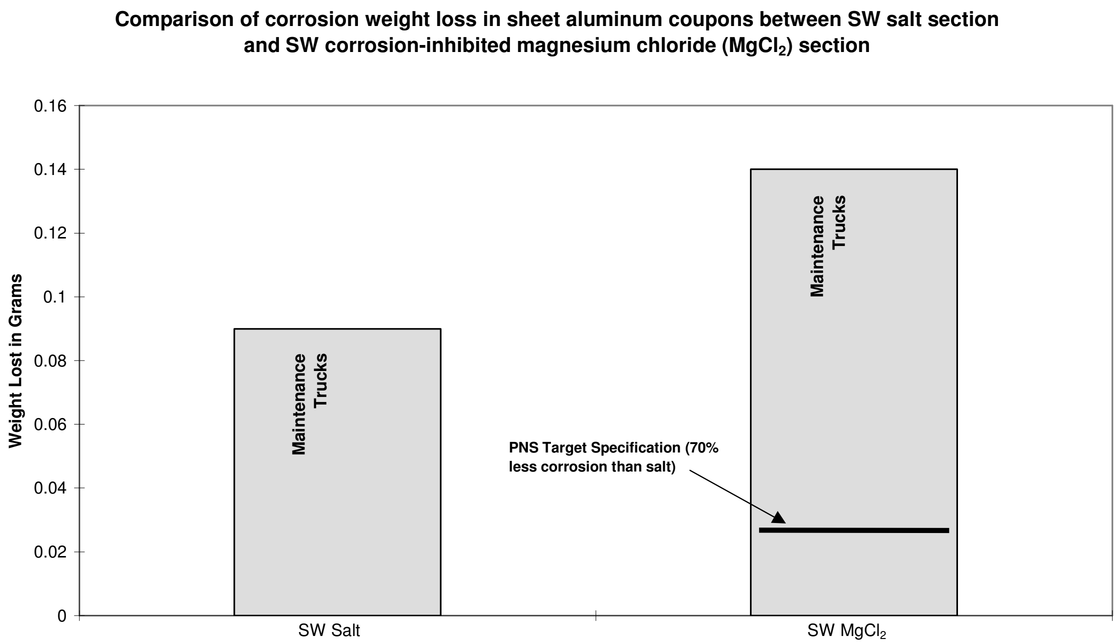

Figure 17: Sheet aluminum coupon corrosion in Southwest Region test sections

The next comparison shows the average weight loss of cast aluminum coupons mounted on SW salt and $MgCl_2$ maintenance trucks. The coupons exposed to $MgCl_2$ had 23% *more* corrosion than similar coupons exposed to salt.

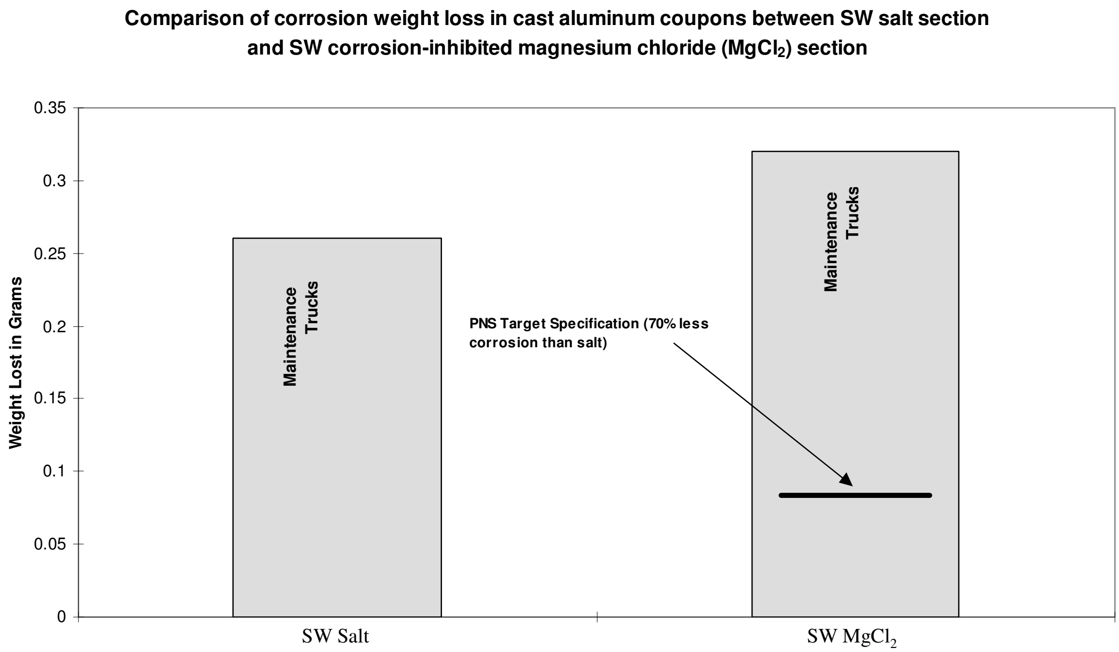

Figure 18: Cast aluminum coupon corrosion in Southwest Region test sections

Discussion: The relative, average corrosion rates found in coupons used on SR 6 in western Washington were generally similar to those found in coupons used in eastern Washington. For steel coupons, the corrosion-inhibited chemicals appeared to provide limited reductions of corrosion for steel and none for aluminum. No coupons were placed on guardrail posts in western Washington where corrosion-inhibited chemicals were used so comparison data with sodium chloride-exposed coupons is not possible.

BRIDGE CORROSION: From a bridge preservation standpoint, areas of concern related to corrosion from anti-icing chemical applications focus primarily on rebar within bridge decks, metal barriers on bridges, and steel structural components underneath the bridge deck. WSDOT bridge office personnel reported no noticeable variations in corrosion levels on any metallic elements of bridges that underwent routine inspections in the salt and corrosion-inhibited chemical sections. It was felt that no meaningful evaluation of corrosion on bridge components could take place in a single year. This type of evaluation would have to be a multi-year evaluation to generate meaningful information related to actual structural bridge corrosion rates.

ENVIRONMENTAL IMPACTS: As part of this pilot project, WSDOT environmental staff conducted field sampling and laboratory analysis to assess the level of chloride residue in the roadside environment. Similar to the other components of this evaluation, the environmental analysis focused on differences in chloride residue in the soil and water for the areas using corrosion inhibited chemicals and those using sodium chloride. The State Departments of Health (responsible for regulation of drinking water) and Ecology (responsible for regulation of surface and ground water) were advised of the pilot project and notified that field measurements would be made. Chloride at a concentration of 250 mg/l is a secondary drinking water standard for taste only. A secondary drinking water standard serves as a guideline and is used by regulatory agencies for chlorides instead of an actively enforced primary standard. Primary standards are used for substances that pose greater potential threats due to toxicity or other properties. Levels of chloride averaging approximately 40mg/l occur naturally in Washington state drinking water. Chloride is not classified as a toxic substance by Washington State Resource agencies. Studies have found that different plant species have widely ranging tolerance levels to chlorides. In general terms, research has shown that freshwater fish begin to demonstrate ill effects from chloride exposure at concentrations between 4000 and 5000 mg/l.

<u>Sampling Methodology:</u> Within each of the four designated sections along I-90 (two sections using corrosion inhibited chemicals and two sections using sodium chloride), four sample locations were identified. These locations were generally chosen based on the potential for chlorides from highway snow and ice control activities to enter nearby waters. However, due to the semi-arid nature of the Columbia River basin, some sections did not have any water bodies nearby that were suitable for sampling. Two sample locations along SR 6 were selected at which standing water was present. All sample locations were recorded into a global positioning system. A total of forty soil, eight surface water, ten sediment, and four drinking water samples were taken during the pre-winter and post-winter sampling efforts. The mild winter weather did not afford ample opportunity for significant sampling opportunities (i.e. runoff from a major snowmelt) during the winter season.

Surface soil samples were collected from each location adjacent to the edge of the pavement, ten feet from the edge of the pavement, and in the sediment at the bottom of a roadside ditch or pond if present (see figure 19). Samples were taken at an approximate depth of three inches below the surface. Care was taken to not include excess organic matter and to minimize the number of rocks present in the sample material.

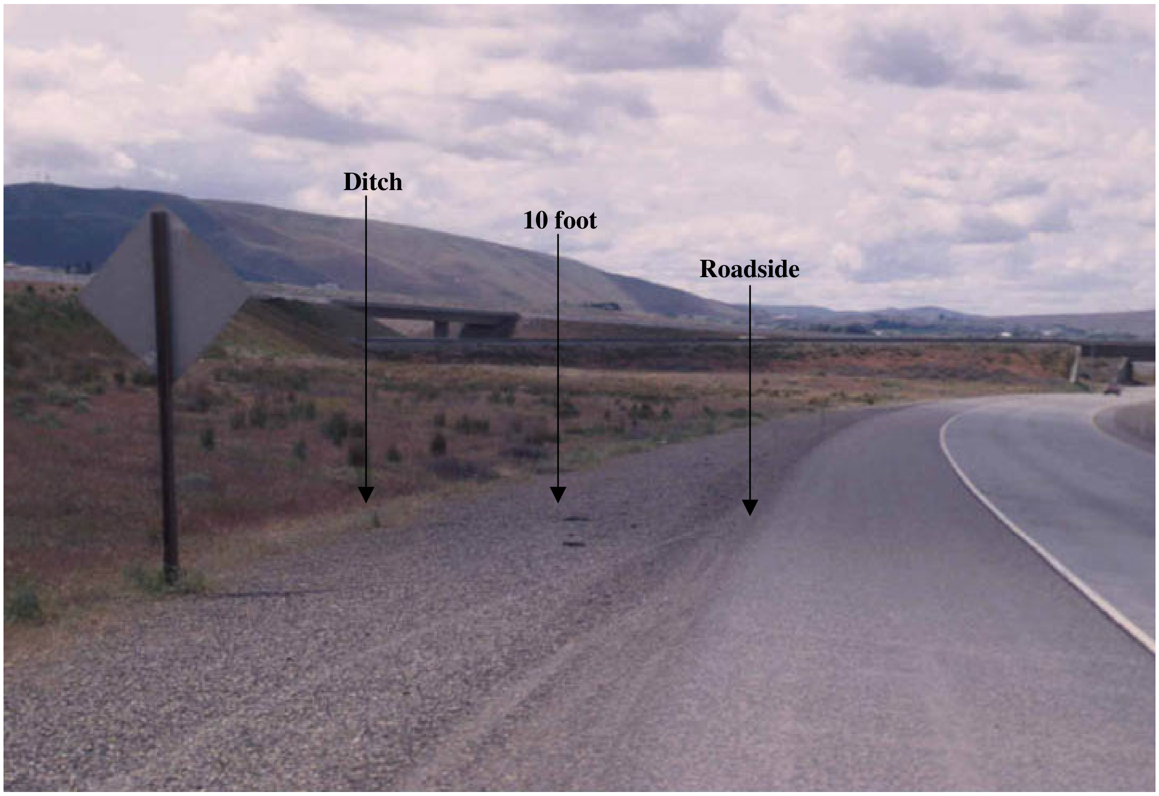

Figure 19: Representation of Soil Sampling Locations

Surface water bodies were sampled only if they were considered non-flowing, e.g. ponds, lakes. Flowing water bodies were not selected because of the dilution factor. Several past studies have shown that in flowing water, chlorides are rapidly diluted leaving little to no detectable chlorides.

One control location was identified within each of the four I-90 segments to measure background chloride levels. These were selected based on the likelihood that the location would be unaffected by any snow and ice control activities. These sites were located at least 100 feet from any roadway or sidewalk. A designated ground water sample was also obtained from each I-90 section from water fountains located at Safety Rest Areas. Each of the Rest Areas is served by a WSDOT-owned well which serves the Rest Area only.

The pre-winter sampling event (sample1) occurred during the summer and fall of 2002. The post-winter sampling event (sample 2) occurred during spring of 2003. The pre-winter and post-winter samples were collected within one foot of each other. Severn Trent Laboratories of Seattle, Washington analyzed all samples for total chloride using analytical method USEPA 300A.

Sample Results: The numerical data for each sample can be found in Appendix 4

The following chart shows a comparison of chloride levels in soils in the salt sections and the corrosion-inhibited chemical sections before the 2002-03 winter season commenced. Each column represents the average of all pre-winter samples taken at each location. While chloride levels in the corrosion-inhibited section are significantly higher than in the salt sections at the roadside locations, chloride levels are comparable at the 10 foot and sediment locations.

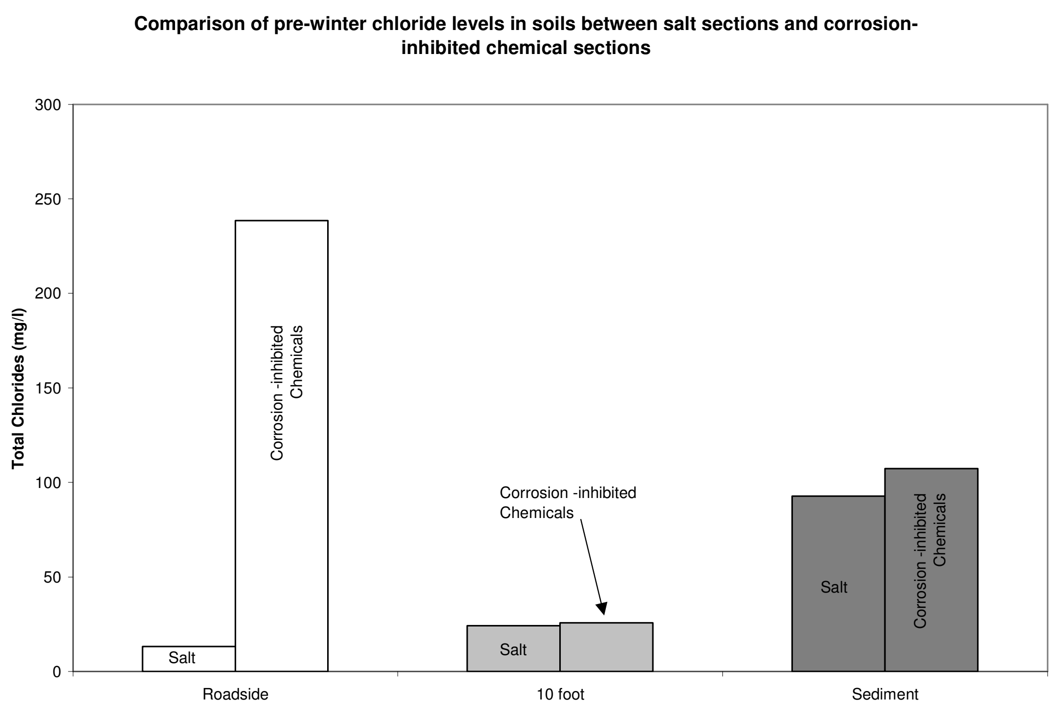

Figure 20: Pre-winter chloride levels in soils

The next chart shows a similar comparison of chloride levels after the end of the 2002-03 winter season. At the roadside locations, chloride levels in the corrosion-inhibited chemical sections were lower than in the pre-winter sampling. Chloride levels in the salt sections remained lower than in the corrosion-inhibited chemical sections. Chloride levels in the 10-foot locations were similar to what they were in the pre-winter sampling. At the sediment locations, chloride levels in the salt sections were approximately twice the levels founds in the corrosion-inhibited chemical sections. Post-winter, sediment chloride levels in the salt sections were higher than they were in the pre-winter sampling. Post-winter, sediment chloride levels in the corrosion-inhibited sections were similar to what they were during pre-winter sampling. The average chloride levels found in soils are relatively low.

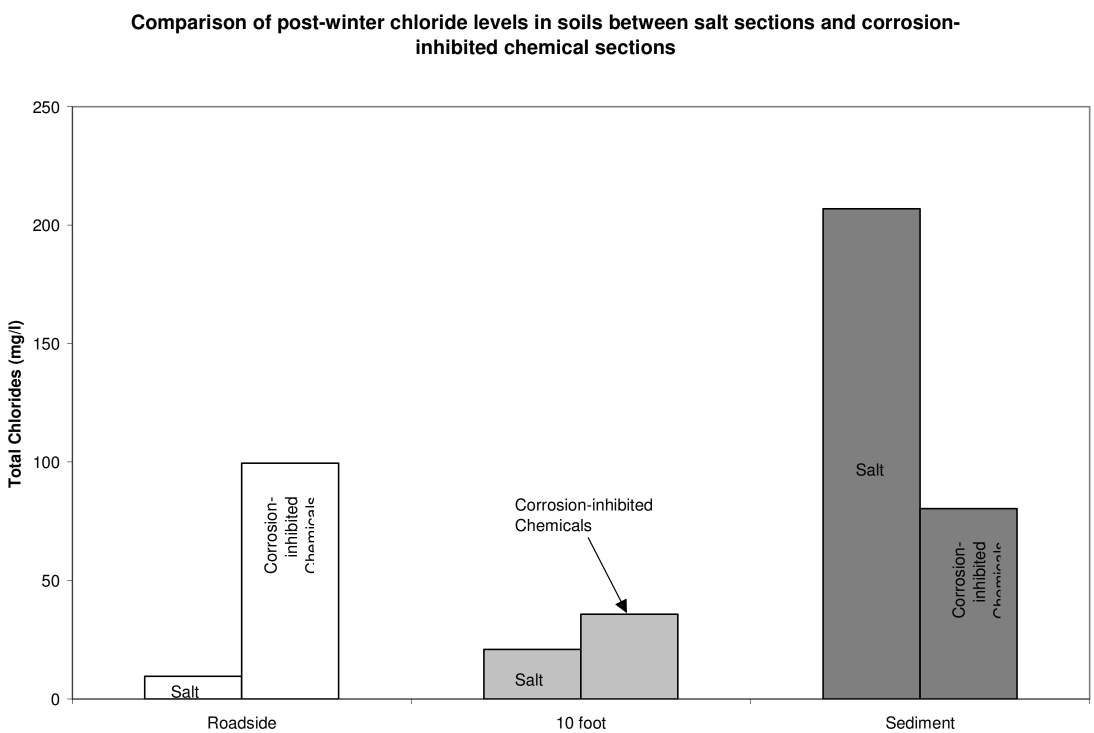

Figure 21: Post-winter chloride levels in soils

The next chart shows a comparison of chloride levels in surface water and drinking water between the salt sections and corrosion-inhibited chemical sections before the 2002-03 winter season commenced. Each column represents the average of all pre-winter samples taken at each location. Chloride levels in both surface waters and drinking waters in the salt section were significantly higher than in the corrosion-inhibited chemicals section.

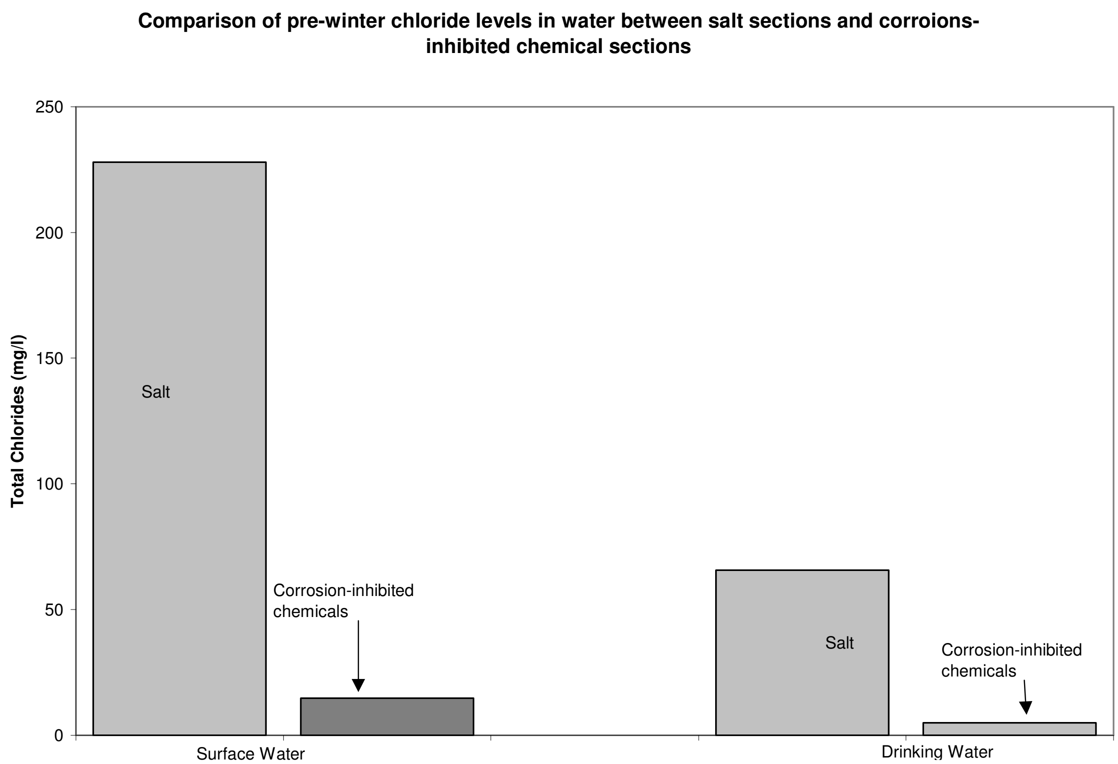

Figure 22: Pre-winter chloride levels in water

The next chart shows a similar comparison of chloride levels after the end of the 2002-03 winter season. The comparative levels of chlorides in surface and drinking water in the salt and corrosion-inhibited chemical sections are very similar to the pre-winter levels. Chloride levels are relatively low compared to related water quality guidelines and other, related reference levels.

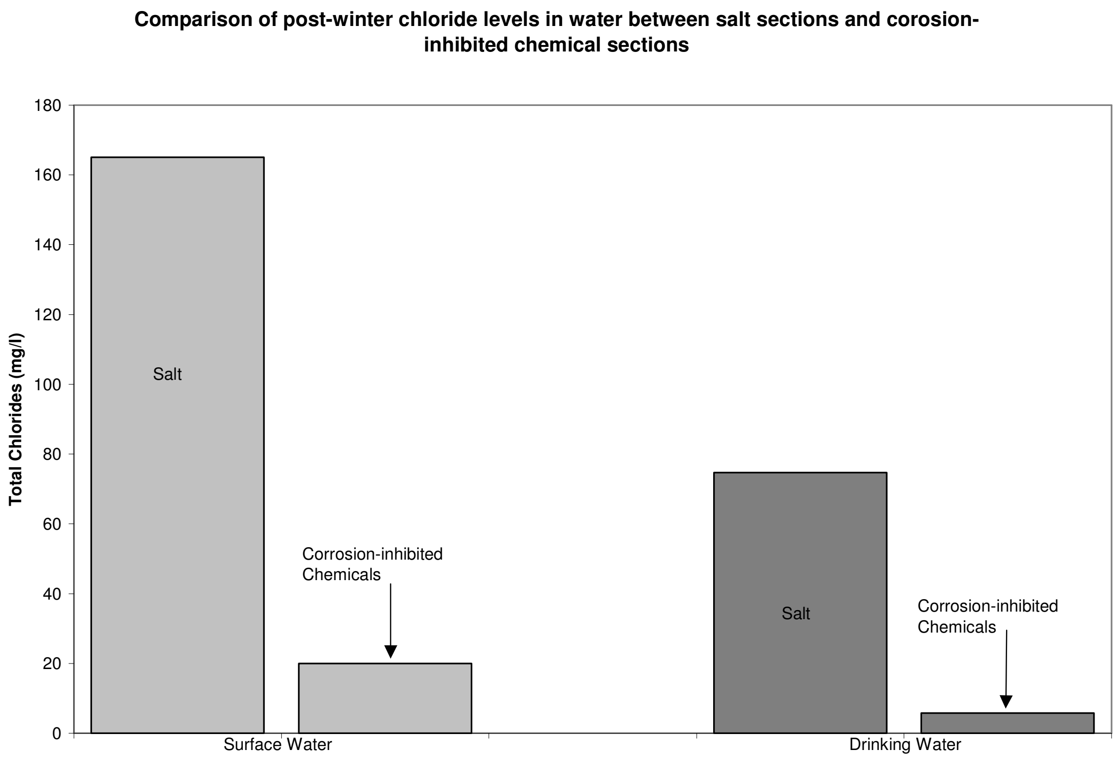

Figure 23: Post-winter chloride levels in water

Chloride levels measured in the control (background) areas were significantly lower than application areas for both sodium chloride and corrosion-inhibited chemicals.

<u>Discussion:</u> There are several variables, which make comparisons of chloride levels in environmental compartments difficult. Sodium chloride and the corrosion-inhibited chemicals both contain chloride ions. Another variable is that both calcium chloride and magnesium chloride have twice the number of chloride ions as sodium chloride. The information does not reveal significant differences in chloride levels resultant of the application of corrosion-inhibited chemicals compared to sodium chloride. The information indicates that WSDOT's application of de-icing chemicals, either corrosion inhibited or sodium chloride is not resulting in chloride levels that are above any state or federal standard or guideline.

The information indicates that chloride concentrations in the soil are highest at the roadside and in the sediment and somewhat lower at the 10 foot sampling stations. This may be due to the fact that in most places along this stretch of I-90, the 10-foot station tends to be on a fairly steep slope. The drinking water data indicates no chloride influence from the anti-icing operation. No significant differences in chloride levels were identified at the end of winter compared to before winter commenced. Since no mid-winter snowmelt events were measured, it is unknown if short-term changes in chloride levels occurred during winter. Control areas show that they have not been affected by chloride applications and are indeed control areas. In general, the winter of 2002/2003 was mild and atypical from a snow and ice maintenance standpoint. As a result, significantly less anti-icing agents were applied to the roadway. More data gathered following another winter application of chemicals might provide a better understanding of significant differences between chemicals if they exist.

SIGNIFICANT PROJECT FINDINGS: This evaluation indicates that the use of corrosion-inhibited chemicals is not resulting in the levels of reduced corrosion for which these chemicals are specified, tested, and purchased. In some scenarios, use of the corrosion-inhibited chemicals resulted in less corrosion than did the use of salt. However, the use of corrosion-inhibited chemicals did not meet the specification target in any of the scenarios evaluated. In other scenarios, the corrosion-inhibited chemicals resulted in more corrosion than did the use of salt. The significant differences in relative corrosion rates and the consistent pattern of not meeting the reduced corrosion specification strongly indicate that the current corrosion specification and related laboratory testing protocol lack a direct and predictable relationship to corrosion rates that actually occur in the roadway and roadside environment.

The corrosion-inhibited chemicals used in this evaluation generally appear to be more aggressive in corroding the sheet and cast aluminum alloys tested than does salt. It is not known whether this is caused by the chloride compound itself or the corrosion-inhibiting additive. The project findings seem to support the increasing complaints from motorists (including a significant amount of complaints from the trucking industry) about corrosion to aluminum. The focus of the development of the PNS corrosion specification was on corrosion to steel. The project findings indicate the specification does not address impacts to sheet and cast aluminum.

The total amount of corrosion weight loss on the steel coupons is much greater than the total amount of corrosion weight loss on the aluminum coupons. The corrosion on the steel coupons takes the form of a uniform layer of rust. In more severe cases of corrosion, this will result in layers of rust and metal scaling from the surface. The corrosion in aluminum takes the form of pitting on the surface. For items such as cast aluminum wheels, this is primarily an aesthetic issue as opposed to a structural or safety issue. However, there are several automotive components in which severe pitting can adversely affect the safety of an automobile's use.

The project findings show some interesting variations in corrosion rates from the use of corrosion-inhibited chemicals. The chemicals meet, or come close to meeting, the corrosion specification when they are delivered to WSDOT maintenance yards. The chemicals' effectiveness (related to reduced corrosion) appears to be reduced after they are applied to the roadway and motor vehicles are exposed to them. As the chemicals are splashed off the roadway or otherwise migrate to the roadside, the findings indicate some significant changes in corrosion rates. In some cases, corrosion rates on the guardrail-mounted coupons were less than on the truck-mounted coupons. In other cases, corrosion rates were more than twice as high at the guardrail location than they were on trucks. This could have significant ramifications to corrosion issues related to bridges, steel re-bar in concrete pavement, and other metal-containing highway features. This is an area on which additional research should focus.

The general performance of salt was found to be favorable in comparison to the corrosion-inhibited chemicals tested. The maintenance crews using salt were able to deliver a Level of Service comparable to that delivered by crews using corrosion-inhibited chemicals. The primary limitation of salt is the relatively limited temperature range in which it will work. The mild winter during the pilot project was well suited for the use of salt. The lack of significant snowfall and black ice events during the pilot project resulted in limited opportunities for a full operational evaluation of salt.

The materials costs of using salt brine and rock salt were significantly less than comparable costs of using corrosion-inhibited chemicals. Use of a factory-built brine maker turned out to be a very cost-effective method of supplying maintenance crews with liquid anti-icers. There are indications that the cost of using salt could be less than that incurred during this evaluation. Looking at costs other than for materials, labor and equipment costs were comparable between those sections using salt and those sections using corrosion-inhibited chemicals. In evaluating environmental costs (impacts), there appears to be little to no difference in impacts between salt use and the use of corrosion-inhibited chemicals. They both are applied in a similar fashion and they both contain comparable levels of chlorides. In evaluating corrosion costs, the evaluation does not provide enough information for a definitive comparison. While the use of corrosion-inhibited chemicals appears to reduce corrosion (and hence some level of potential, eventual cost savings) of steel in motor vehicles, the findings indicate the possibility of less corrosion reduction (and hence some level of potential, eventual cost increases) as chemicals move from the roadway to the roadside. Also, while the use of corrosion-inhibited chemicals appears to reduce corrosion costs related to steel, it appears to increase corrosion related to aluminum. Some costs would also be associated with these impacts.

Recommended Actions: This evaluation highlights some very important issues. Related policy decisions should be made only after a thorough analysis of related data and comprehensive discussions of costs and benefits. This evaluation provides limited data to support such decisions and represents the first of many steps in that direction.

Considering the mild winter weather and limited scope of the corrosion analysis, the evaluation should be extended for at least one additional winter season. This will provide an opportunity for maintenance to continue comparing salt and corrosion-inhibited chemicals under more "normal" winter conditions. It will also provide an opportunity to add another year's worth of information to our body of knowledge on this topic.

There are many aspects of this evaluation that could be further refined through more formal research methods. This would diversify and build upon the information gained from this project. For example, a research project could identify the variables both on and off the roadway environment that impact corrosion. These variables could then be more closely managed during an evaluation to strengthen the accuracy of the data.

Policy decisions regarding the use of salt or corrosion-inhibited chemicals should be made in the context of asset management rather than the narrower focus of operations management. Immediate costs/savings related of using certain snow and ice control chemicals and costs/savings related to improved motorist safety/mobility need to be balanced with the longer-term costs/savings such as those of corrosion to motor vehicles and the preservation of bridges and pavements.

The corrosion data focuses on how field performance of the corrosion-inhibited chemicals relates to the chemical's laboratory performance. Additional research should be conducted to help identify corrosion rates to different metals that are acceptable to highway asset managers and the motoring public. In other words, what levels of corrosion can we live with to get the safety and mobility benefits that the use of snow and ice control chemicals provides?

The currently used corrosion specification and related laboratory procedures should be re-evaluated to identify ways to improve its relationship to actual corrosion rates.

Appendix 1: Snow and Ice Control Level of Service (LOS) Data

TEST (SALT) SECTIONS

LOCATION	SR	MILEPOST	SITE #	NUMBER OF COMPLETED SURVEYS	AVG. LOS RATING	LETTER GRADE EQUIVALENT
SC Test (Salt)	90	120-122	522	14	1.5	A
	90	125-127	523	15	1.4	A
Section LOS					**1.5**	**A**
Eas. Test (Salt)	90	237-239	614	16	1.3	A
Section LOS					**1.3**	**A**
SW Test (Salt)	6	10-12	421	5	1.9	A-
	6	21-23	438	5	1.9	A-
	6	31-33	437	5	1.8	A-
Section LOS					**1.9**	**A-**

CONTROL (CORROSION-INHIBITED CHEMICALS) SECTIONS

LOCATION	SR	MILEPOST	SITE #	NUMBER OF COMPLETED SURVEYS	AVG. LOS RATING	LETTER GRADE EQUIVALENT
NC Control (Corrosion-Inhibited Chemicals	90	152-154	211	6	1.0	A+
	90	182-184	216	3	1.0	A+
Section LOS					**1.0**	**A+**
Eas. Control (Corrosion-inhibited Chemicals)	90	268-270	621	5	1.1	A+
	90	278-280	602	5	1.8	A-
	90	290-292	622	2	1.0	A+
Section LOS					**1.3**	**A**
SW Control (Corrosion-inhibited Chemicals)	508	10-12	412	2	3.5	C
	101	39-41	422	4	1.5	A
	101	65-67	423	7	2.4	B
	105	4-6	424	3	3.0	C+
Section LOS					**2.6**	**B**

Appendix 2: Laboratory Procedure for Corrosion Testing

(WSDOT Test Method T 418)

1. SCOPE

   The weight loss of steel coupons subjected to corrosion by deicing salts for a given period of time is determined. This weight loss is converted to mils penetration per year of the steel surface by the deicing salt. The ratio of the deicing salt sample to a sodium chloride control sample is reported to provide a means to evaluate and compare the corrosion rates of different deicing salts. (This procedure is a modification of NACE Standard TM-01-69 (1976 Revision)).

2. APPARATUS

   a. Timer, adjustable, that can be set for a 50 minute (up position) and a 10 minute (down position) cycle every hour, and able to cycle for 72 hours.

   b. Immersion testing device capable of automatically subjecting the coupons to an immersion/no immersion cycle. A device with a bar, configured like a crank to which a line from the coupon holder is attached, with an electric motor, governed by the timer, that cycles the crank up and down, is one type of tester.

   c. 500 Erlenmeyer flasks fitted with one-hole rubber stoppers, one flask for each sample plus one for a distilled water control and one for a sodium chloride standard.

   d. Non-corrosive (e.g., polyethylene) coupon holders attached to the immersion testing device with non-corrosive line (e.g., polypropylene fish line). Each coupon holder to hold three coupons.

   e. Coupons, non-galvanized $^{1}/_{2}$ in. (13 mm) flat steel washers having the approximate dimensions of 1.38 in. (35 mm) outside diameter by 0.56 in. (14 mm) inside diameter by 0.12 in. (3 mm) thick. Coupons must meet ASTM F436, Type 1, with a Rockwell Hardness of C 38-45. Three coupons are needed for each sample.

   f. Polypropylene bottlers, for sample dissolution, one for each sample.

   g. Balance, accurate to 0.0001 g.

   h. Metal stamp numbering set.

   i. Dial Caliper to measure coupons, accurate to 0.01 mm.

3. REAGENTS

   a. Hydrochloric Acid cleaning solution. Make by dissolving 50 g $SnCl_2$ (stannous chloride) and 20 g $SbCl_3$ (antimony trichloride) in 1000 ml of concentrated Hydrochloric Acid.

   b. Distilled water conforming to ASTM D 1193 Type II.

   c. Chloroform, technical grade.

   d. Acetone, technical grade.

   e. Sodium Chloride standard. Make a 3 percent by weight solution of reagent grade Sodium Chloride in distilled water.

   f. Hydrochloric Acid, 1 + 1.

4. PREPARATION OF THE COUPONS

   a. Wipe each coupon with a suitable solvent to remove grease and oil.

   b. Examine each coupon for metallurgical abnormalities and reject those that are suspect to flaws.

   c. Acceptable coupons are stamped for identification.

   d. Coupons are acid etched with 1+1 HCl for approximately 2-3 minutes.

   e. The coupons are quickly rinsed with tap water, then distilled water, wiped dry and placed in chloroform.

   f. When the coupons are removed from the chloroform for use, they are placed on a paper-lined tray (not touching each other) and allowed to air dry in a ventilated hood for a minimum of 15 minutes.

   g. Coupons are measured as specified in Section 5. (Note: If latex gloves are not worn during measuring, the coupons should be rinsed again and dried as prescribed above prior to -weighing. This will remove any oils that may be transferred to the coupons.)

   h. Each coupon shall be weighed to a constant weight. The constant weight is obtained when two consecutive weighings of each coupon are within a minimum of 0.5 milligrams of each other. Removal of incidental flash rusting prior to weighing is not necessary.

   i. Three coupons are used in each chemical product solution and for the distilled water and Sodium Chloride controls.

5. MEASURING THE COUPONS

The outside diameter, inside diameter, and the thickness of each coupon is measured twice at 90 degrees from each initial reading and the averages calculated for each measurement. The -averages are than used to calculate the surface area of each coupon with the following formula:

$$A = (3.1416/2)(D^2-d^2) + 3.1416(t)(D) + 3.1416(t)(d)$$

Where D = average outside diameter
d = average inside diameter
t = average thickness

6. SAMPLE PREPARATION

Make a 3 percent by weight solution of each deicing salt by weighing 30.00 g (as received) of the sample and dissolving in 970.00 g of distilled water. Allow the solutions to sit a minimum of 12 hours in polyethylene bottles to insure maximum solubility and to allow for any reactivity (i.e., heat of hydration and heat of solution).

7. PROCEDURE

Approximately 300 milliliters of the deicing solution as mixed with distilled water is placed into a 500 ml Erlenmeyer flask. Each flask is equipped with a rubber stopper that has been drilled to allow a line to run through it. One end of the line is attached to a rotating bar and the other end of the line is attached to a plastic frame made to hold the three coupons inside the flask. The rotating bar is controlled by an electric timer that lowers the coupon holding apparatus into the solution for 10 minutes then raises the coupon holding apparatus out of the solution for 50 minutes but still keeps the coupons inside of the flask for the entire duration of the test. The corrosion test is run for 72 hours. No agitation of the solution is made during the corrosion test.

Corrosion tests are conducted at normal room temperature. The room temperature is to be recorded daily during the operation of the test. The room temperature shall be taken with a calibrated thermometer located next to the corrosion-testing instrument.

8. CLEANING OF THE COUPONS

The coupons are removed from the solution after 72 hours. They are placed in glass beakers containing the Hydrochloric Acid cleaning solution. (Note: The fumes given off by the acid during cleaning contain gases formed from the antimony and are extremely hazardous, this portion of the cleaning must be conducted under a fume hood).

After 15 minutes of cleaning the coupons are removed from the cleaning acid, rinsed with tap water, then distilled water, and wiped with a cloth to clean any deposits from the coupons. They are then returned to the cleaning acid and the procedure is repeated. After cleaning, the coupons are rinsed in chloroform, air-dried, and weighed.

Each coupon shall be weighed to a constant weight. Constant weight is obtained when two consecutive weighings of each coupon are within a minimum of 0.5 milligrams of each other.

9. EVALUATION OF CORROSION

The weight loss of each coupon is determined by subtracting the final weight from the original weight. The corrosion rate for each coupon is expressed as mils penetration per year (MPY) by the following formula:

MPY = [(weight loss (milligrams)](534)/[(area)(time)(metal density*)]

* metal density for steel is 7.85 g/cc

The final MPY value for each solution is determined by calculating an average of the three individual coupons. (Note: Wide variation of MPY of individual coupons inside the same flask typically indicates contamination of a coupon. If variation of individual MPY is too great to -determine consistent data the test should be repeated. Typically coupon variation may run plus or minus 3 MPY).

10. REPORTING RESULTS

Results shall be reported in Percent Effectiveness (also referred to as “Percent as Corrosive as NaCl”). Results equal to or less than 30% are passing.

The MPY is determined as above for the deicing salt samples, the distilled water blank and for the sodium chloride standard.

The MPY determined for the distilled water blank is subtracted from the MPY value obtained for the deicing samples to arrive at an adjusted deicing sample MPY. Likewise, the distilled water blank is subtracted from the MPY value of the sodium chloride standard to obtain the adjusted NaCl standard MPY.

The adjusted deicing sample MPY is divided by the adjusted NaCl standard MPY and multiplied by 100 to obtain the corrosion of the sample as a percent of the sodium chloride corrosion result.

% Effectiveness = [adjusted deicing sample MPY/adjusted NaCl standard MPY] x 100

Appendix 3: Metal Coupon Corrosion Data

(All weight measures are in grams)

SALT PILOT PROJECT-CORROSION DATA																	
SOUTH CENTRAL REGION - SALT/TEST SECTION																	
		Hours			**Mileage**				**Cold Rolled Steel**			**Aluminum Sheet 5182**			**Cast Aluminum A356**		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	8E12-9	2366	2575	209	48177	53529	5352	1A	96.883	92.452	4.431	41.046	40.992	0.054	254.512	254.341	0.171
								1B	97.112	93.070	4.042	41.286	41.235	0.051	255.397	255.228	0.169
2	6E13-1	7931	8171	240	201842	208035	6193	2A	96.886	90.076	6.810	41.086	41.051	0.035	263.851	263.600	0.251
								2B	97.342	90.779	6.563	41.311	41.268	0.043	250.509	250.302	0.207
Average Weight Loss - Maintenance Trucks											**5.462**			**0.046**			**0.199**
3	5E20-7				71876	78657	6781	3A	96.482	89.062	7.420	41.065	40.919	0.146	248.963	248.749	0.214
								3B	96.753	89.182	7.571	41.278	41.126	0.152	248.846	248.680	0.166
Average Weight Loss - Supervisor Truck											**7.496**			**0.149**			**0.190**
Remote									**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**
Roadside									**97.518**	**91.212**	**6.306**	**41.412**	**41.386**	**0.026**	**254.277**	**254.208**	**0.069**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

Appendix 3: Metal Coupon Corrosion Data

(All weight measures are in grams)

SALT PILOT PROJECT-CORROSION DATA

SOUTH CENTRAL REGION - SALT/TEST SECTION

		Hours			**Mileage**				**Cold Rolled Steel**			**Aluminum Sheet 5182**			**Cast Aluminum A356**		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	8E12-9	2366	2575	209	48177	53529	5352	1A	96.883	92.452	4.431	41.046	40.992	0.054	254.512	254.341	0.171
								1B	97.112	93.070	4.042	41.286	41.235	0.051	255.397	255.228	0.169
2	6E13-1	7931	8171	240	201842	208035	6193	2A	96.886	90.076	6.810	41.086	41.051	0.035	263.851	263.600	0.251
								2B	97.342	90.779	6.563	41.311	41.268	0.043	250.509	250.302	0.207
Average Weight Loss - Maintenance Trucks											**5.462**			**0.046**			**0.199**
3	5E20-7				71876	78657	6781	3A	96.482	89.062	7.420	41.065	40.919	0.146	248.963	248.749	0.214
								3B	96.753	89.182	7.571	41.278	41.126	0.152	248.846	248.680	0.166
Average Weight Loss - Supervisor Truck											**7.496**			**0.149**			**0.190**
Remote									**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**
Roadside									**97.518**	**91.212**	**6.306**	**41.412**	**41.386**	**0.026**	**254.277**	**254.208**	**0.069**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

Appendix 3: Metal Coupon Corrosion Data

(All weight measures are in grams)

NORTH CENTRAL REGION - CORROSION-INHIBITED CHEMICAL/CONTROL SECTION																	
		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1								1A	96.688								
								1B	97.243								
2	6B13-49	370	518	148	11013	15909	4896	2A	97.025	93.938	3.087	41.507	41.477	0.030	256.195	255.980	0.215
								2B	97.796	94.911	2.885	41.816	41.794	0.022	257.416	257.336	0.080
3	19B8-3	1607			27765			3A	97.376	95.128	2.248	41.706	41.496	0.210	264.473	264.282	0.191
								3B	97.482	95.481	2.001	41.493	41.193	0.300	259.653	259.522	0.131
Average Weight Loss - Maintenance Trucks											**2.555**			**0.141**			**0.154**
7	5B10-32							7A	97.428	94.374	3.054	41.244	41.073	0.171	256.163	256.044	0.119
								7B	97.728	94.719	3.009	41.420	41.248	0.172	263.090	262.950	0.140
Average Weight Loss - Supervisor Truck											**3.032**			**0.172**			**0.130**
Remote									**96.227**	**95.350**	**0.877**	**41.266**	**41.261**	**0.005**	**257.071**	**257.046**	**0.025**
Roadside									**96.783**	**89.428**	**7.355**	**41.266**	**41.205**	**0.061**	**255.759**	**255.588**	**0.171**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

Appendix 3: Metal Coupon Corrosion Data

(All weight measures are in grams)

EASTERN REGION (AREA 3) - SALT/TEST SECTION																	
		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	6G13-44	3521	3727	206	104676	111150	6474	1A	96.905	85.926	10.979	40.971	40.763	0.208	252.486	252.170	0.316
								1B	96.897	86.278	10.619	41.257	40.962	0.295	246.980	246.803	0.177
2	8G13-02	741	959	218	18601	24202	5601	2A	96.611	91.044	5.567	40.948	40.920	0.028	256.784	256.468	0.316
								2B	97.111	92.502	4.609	41.127	41.090	0.037	251.407	251.147	0.260
3	6B13-43	2782	2941	159	83700	88437	4737	3A	96.490	86.305	10.185	40.680	40.368	0.312	252.668	252.420	0.248
								3B	96.518	85.460	11.058	41.167	40.820	0.347	260.157	259.907	0.250
4	6G13-70	1222	1345	123	26239	28991	2752	4A	96.286	88.450	7.836	40.909	40.824	0.085	259.964	259.757	0.207
								4B	97.548	88.927	8.621	41.090	41.006	0.084	243.874	243.747	0.127
5	6G6-95							5A	96.656	88.314	8.342	40.994	40.875	0.119	243.425	243.272	0.153
								5B	97.560	88.694	8.866	41.214	41.037	0.177	252.697	252.516	0.181
6	6G13-84	70	96	26	3035	3707	672	6A	96.952	91.942	5.010	41.072	41.028	0.044	246.432	246.290	0.142
								6B	96.862	91.849	5.013	41.005	40.932	0.073	243.390	243.241	0.149
7	6G13-47	2073	2201	128	44581	47561	2980	7A	96.742	87.082	9.660	40.954	40.847	0.107	256.058	255.824	0.234
								7B	96.572	88.048	8.524	41.149	40.997	0.152	251.411	251.170	0.241
8	6G13-38	3339	3536	197	104112	110045	5933	8A	96.534	81.807	14.727	41.031	40.648	0.383	252.902	252.610	0.292
								8B	96.788	78.274	18.514	41.148	40.896	0.252	253.824	253.488	0.336
9	8G29-2				108192	109788	1596	9A	95.982	93.260	2.722	40.947	40.922	0.025	260.489	260.384	0.105
								9B	96.854	93.755	3.099	41.317	41.280	0.037	256.980	256.870	0.110
Average Weight Loss - Maintenance Trucks											**8.553**			**0.154**			**0.214**
10	5E20-44							10A	96.215	88.102	8.113	40.964	40.833	0.131	252.745	252.608	0.137
								10B	97.083	88.791	8.292	41.169	41.033	0.136	249.102	248.946	0.156
Average Weight Loss - Supervisor Truck											**8.203**			**0.133**			**0.147**
Remote									**95.931**	**95.557**	**0.374**	**40.832**	**40.830**	**0.002**	**265.098**	**265.083**	**0.015**
Roadside									**97.404**	**91.043**	**6.361**	**41.188**	**41.153**	**0.035**	**262.917**	**262.748**	**0.169**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

Appendix 3: Metal Coupon Corrosion Data

(All weight measures are in grams)

EASTERN REGION (AREA 1) - CORROSION-INHIBITED CHEMICAL/CONTROL SECTION																	
		Hours			**Mileage**				**Cold Rolled Steel**			**Aluminum Sheet A562**			**Cast Aluminum**		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	8B12-8	3228	3484	256	58483	63595	5112	1A	97.377	87.524	9.853	41.480	41.224	0.256	255.458	255.034	0.424
								1B	97.188	87.594	9.594	41.677	41.414	0.263	258.660	258.138	0.522
2	6G13-39	4145	4315	170	93631	96907	3276	2A	97.076	92.184	4.892	41.550	41.350	0.200	254.994	254.836	0.158
								2B	97.110	90.912	6.198	41.747	41.545	0.202	255.785	255.582	0.203
3	6G6-3	2772	2855	83	57481	59417	1936	3A	96.633	90.941	5.692	41.559	40.938	0.621	254.838	254.685	0.153
								3B	96.511	88.929	7.582	41.824	41.340	0.484	256.156	255.972	0.184
4	6G13-71	2463	2696	233	57985	63234	5249	4A	96.470	87.758	8.712	41.636	41.376	0.260	255.896	255.694	0.202
								4B	96.971	87.727	9.244	41.797	41.636	0.161	255.061	254.870	0.191
5	6G13-79	287	374	87	6115	7866	1751	5A	97.446	93.775	3.671	41.505	41.428	0.077	254.545	254.356	0.189
								5B	97.369	92.246	5.123	41.728	41.668	0.060	257.031	256.879	0.152
6	6G13-40	4074	4238	164	95401	99073	3672	6A	96.691	91.819	4.872	41.219	41.129	0.090	254.723	254.572	0.151
								6B	97.403	92.208	5.195	41.398	41.299	0.099	263.903	263.764	0.139
7	6G13-63	1685	1847	162	39267	42865	3598	7A	96.976	91.171	5.805	41.189	40.477	0.712	254.858	254.614	0.244
								7B	96.833	92.245	4.588	41.449	41.045	0.404	254.239	253.943	0.296
8	8G12-11	3270	3367	97	84676	86638	1962	8A	96.810	91.978	4.832	41.483	41.218	0.265	256.078	255.840	0.238
								8B	96.771	91.564	5.207	41.422	41.144	0.278	249.664	249.465	0.199
9	6G13-76	958	1197	239	21090	26183	5093	9A	96.510	93.737	2.773	41.346	39.838	1.508	252.722	252.406	0.316
								9B	97.286	91.900	5.386	41.400	40.250	1.150	254.107	253.846	0.261
10	8G12-7	1993	2165	172	28706	31511	2805	10A	96.578	91.050	5.528	41.344	41.248	0.096	254.834	254.600	0.234
								10B	96.775	91.546	5.229	41.201	41.112	0.089	257.881	257.646	0.235
Average Weight Loss - Maintenance Trucks											**5.999**			**0.364**			**0.235**
11	5G20-40							11A	97.233	91.296	5.937	41.297	41.183	0.114	255.914	255.786	0.128
								11B	97.001	90.986	6.015	41.390	41.284	0.106	257.119	256.984	0.135
Average Weight Loss - Supervisor Pickup Truck											**5.997**			**0.342**			**0.226**
Remote									**96.371**	**95.783**	**0.588**	**41.006**	**41.002**	**0.004**	**260.442**	**260.390**	**0.052**
Roadside									**97.695**	**90.741**	**6.954**	**41.217**	**41.196**	**0.021**	**254.819**	**254.728**	**0.091**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

Appendix 3: Metal Coupon Corrosion Data

(All weight measures are in grams)

SOUTHWEST REGION - SALT/TEST SECTION																	
		Hours			**Mileage**				**Cold Rolled Steel**			**Aluminum Sheet A562**			**Cast Aluminum**		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
2	8D29-4							3A	97.610	93.921	3.689	41.477	41.442	0.035	254.312	254.186	0.126
								3B	98.653	93.860	4.793	41.728	41.680	0.048	264.843	264.722	0.121
3	6D6-95							4A	97.280	90.246	7.034	41.507	41.390	0.117	254.035	253.652	0.383
								4B	98.063	88.234	9.829	41.782	41.629	0.153	254.803	254.398	0.405
Average Weight Loss - Maintenance Trucks											**6.336**			**0.088**			**0.259**
Remote - 150' off HWY 6 MP 25									97.797	97.326	0.471	41.617	41.608	0.009	243.354	243.305	0.049
Remote - Hope Creek Pit - 200' off HWY 6									97.331	96.774	0.557	41.397	41.388	0.009	254.060	254.102	-0.042
Average Weight Loss - Remote Locations											**0.343**			**0.009**			**0.004**
Guard Rail Post Hwy 6									98.422	95.536	2.886	41.734	41.718	0.016	262.672	262.565	0.107
Sign Post HWY 6 MP 46									98.606	94.169	4.437	41.738	41.708	0.030	263.948	263.823	0.125
Average Weight Loss - Roadside Locations											**3.662**			**0.023**			**0.116**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010
SOUTHWEST REGION - CORROSION-INHIBITED CHEMICAL/CONTROL SECTION																	
		Hours			**Mileage**				**Cold Rolled Steel**			**Aluminum Sheet A562**			**Cast Aluminum**		
Rack	Equip #	start	end	diff	start	end	diff	Coupon	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	6D13-34							2A	97.433	91.164	6.269	41.369	41.136	0.233	263.572	263.025	0.547
								2B	98.219	90.997	7.222	41.693	41.452	0.241	264.602	264.050	0.552
4	8D29-2							5A	97.890	94.886	3.004	41.492	41.470	0.022	256.804	256.720	0.084
								5B	98.090	94.138	3.952	41.817	41.756	0.061	264.189	264.098	0.091
Average Weight Loss - Maintenenace Trucks											**5.112**			**0.139**			**0.318**

Appendix 4: Environmental Sampling Data

SC REGION SALT SECTION

Sample ID #	Matrix	First Sample Date	Total Chloride (mg/kg)	PQL	Second Sample Date	Total Chloride (mg/kg)	PQL	Change in Value (mg/kg)
1-1-1	Solid	7/16/2002	18.1	2.77	4/30/2003	21.2	2.93	3.10
1-1-2	Solid	7/16/2002	18.8	2.55	4/30/2003	68.1	3.11	49.30
1-1-3	Solid	7/16/2002	13.5	6.52	4/30/2003	18.3	6.18	4.80
1-2-1	Solid	7/16/2002	56.8	2.97	4/30/2003	16.3	2.94	-40.50
1-2-2	Solid	7/16/2002	2.59	2.7	4/30/2003	8.71	2.94	6.12
1-2-3	Solid	7/16/2002	3.41	3.51	4/30/2003	15.4	4.12	11.99
1-3-1	Solid	7/16/2002	4.16	2.98	4/30/2003	10.6	3.01	6.44
1-3-2	Solid	7/16/2002	65	2.64	4/30/2003	8.97	3.12	-56.03
1-4-1	Solid	7/16/2002	8.47	2.87				
1-4-2	Solid	7/16/2002	ND	3				
1-C-RA	Solid	7/16/2002	1.11	3	4/30/2003	1.9	3.36	0.79
1-RA-DW	Liquid	7/16/2002	4.52	0.3	4/30/2003	5.45	0.3	0.93

NC REGION CORROSION-INHIBITED CHEMICAL SECTION

Sample ID #	Matrix	First Sample Date	Total Chloride (mg/kg)	PQL	Second Sample Date	Total Chloride (mg/kg)	PQL	Change in Value (mg/kg)
2-1-1	Solid	7/11/2002	4.59	3.08	4/30/2003	21.4	3.12	16.81
2-1-2	Solid	7/11/2002	13.9	2.64	4/30/2003	35.3	3.12	21.40
2-1-3	Solid	7/11/2002	138	16.3	4/30/2003	7.64	3.35	-130.36
2-1-W	Liquid	7/11/2002	21.5	6	4/30/2003	28.5	0.3	7.00
2-2-1	Solid	7/11/2002	2.27	2.91	4/30/2003	15.1	2.94	12.83
2-2-2	Solid	7/11/2002	42.9	3.31	4/30/2003	128	3.04	85.10
2-2-3	Solid	7/11/2002	2.76	3.06	4/30/2003	200	3.5	197.24
2-2-W	Liquid	7/11/2002	3.99	3	4/30/2003	6.38	0.3	2.39
2-3-1	Solid	7/11/2002	227	3.13	*			*
2-3-2	Solid	7/11/2002	96.8	3	*			*
2-3-3	Solid	7/11/2002	330	2.91	*			*
2-3-W	Liquid	7/11/2002	3.59	0.6	*			*
2-4-1	Solid	7/11/2002	212	2.8	4/30/2003	77.4	3.06	-134.60
2-4-2	Solid	7/11/2002	38.9	2.62	4/30/2003	42.2	3.21	3.30
2-4-3	Solid	7/11/2002	ND	3.26	4/30/2003	ND	3.6	ND
2-4-W	Liquid	7/11/2002	2.78	0.6	4/30/2003	1.94	0.3	-0.84
2-C-RA	Solid	7/11/2002	2.13	2.64	4/30/2003	ND	2.89	-2.13
2-RA-DW	Liquid	7/11/2002	9.07	0.3	4/30/2003	9.17	0.3	0.10

EASTERN REGION SALT SECTION

3-1-1	Solid	7/11/2002	7.75	2.92	5/1/2003	ND	3.16	-7.75
3-1-2	Solid	7/11/2002	41.1	3.08	5/1/2003	29.2	3.32	-11.90
3-2-1	Solid	7/11/2002	2.78	2.75	5/1/2003	ND	3.06	-2.78
3-2-2	Solid	7/11/2002	7.75	3.07	5/1/2003	7.21	2.88	-0.54
3-3-1	Solid	7/11/2002	2.14	2.79	5/1/2003	3.07	3.13	0.93
3-3-2	Solid	7/11/2002	7.74	2.89	5/1/2003	13.8	3.75	6.06
3-4-1	Solid	7/11/2002	5.77	2.63	5/1/2003	8.98	3.15	3.21
3-4-2	Solid	7/11/2002	51.4	2.81	5/1/2003	2.5	3.23	-48.90
3-4-3	Solid	7/11/2002	177	19.6	5/1/2003	190	3.67	13.00
3-4-W	Liquid	7/11/2002	228	15	5/1/2003	165	3	-63.00
3-C-RA	Solid	7/11/2002	1.03	2.61	5/1/2003	207	3.27	205.97
3-RA-DW	Liquid	7/11/2002	127	3	5/1/2003	144	3	17.00

EASTERN REGION CORROSION-INHIBITED CHEMICAL SECTION

4-1-1	Solid	7/11/2002	ND	2.73	5/1/2003	ND	3.03	-2.73
4-1-2	Solid	7/11/2002	6.01	2.77	5/1/2003	ND	3.17	-2.77
4-1-3	Solid	7/11/2002	107	7.17	5/1/2003	100	4.48	-7.00
4-2-1	Solid	7/11/2002	253	2.81	5/1/2003	ND	3.07	-2.81
4-2-2	Solid	7/11/2002	4.47	2.88	5/1/2003	3.39	3.07	-1.08
4-2-3	Solid	7/11/2002	8.55	3.53	5/1/2003	13.8	3.75	5.25
4-2-W	Liquid	7/11/2002	30.8	3	5/1/2003	43.2	0.6	12.40
4-3-1	Solid	7/11/2002	ND	2.81	5/1/2003	ND	3.19	ND
4-3-2	Solid	7/11/2002	ND	3.01	5/1/2003	ND	3.1	-3.01
4-4-1	Solid	7/11/2002	1210	13.1	5/1/2003	645	14.4	-565.00
4-4-2	Solid	7/11/2002	2.1	3.01	5/1/2003	8.06	3.09	5.96
4-C-RA	Solid	7/11/2002	ND	16.5	5/1/2003	1.74	3.33	1.74
4-RA-DW	Liquid	7/11/2002	0.989	0.3	5/1/2003	2.38	0.3	1.39

SW REGION SALT SECTION

1-1	Solid	9/12/2002	10.6	2.81	5/20/2003	ND	3.06
1-2	Solid	9/12/2002	643	12	5/20/2003	5.06	3.26
1-3	Solid	9/12/2002	203	13.6	5/20/2003	14.3	11.5
1-4	Liquid	9/12/2002	23.7	0.6	5/20/2003	2.78	0.3
2-1	Solid	9/12/2002	13.4	2.78	5/20/2003	1.86	3.04
2-2	Solid	9/12/2002	173	20.9	5/20/2003	12	4.78
2-4	Liquid	9/12/2002	11.4	0.6	5/20/2003	2.75	0.3

Notes: In Sample ID #'s, the first digit identifies the project section, the second digit identifies a sample location within the project section, and the third digit identifies the sample's proximity to the pavement ("1" is roadside or at the edge of pavement, "2" is 10 feet from roadside, "3" is sediment in ditch or pond). "C" is for a control or background sample. "W" is a water sample. "RA" is a sample taken at a Highway Rest Area. "DW" is a drinking water sample.

In the column headings, "PQL" stands for Practical Quantification Limit which is synonomous with level of detection.